Pearson Edexcel Level 3 GCE

Friday 20 June 2025

Afternoon (Time: 1 hour 30 minutes) | Paper reference **9FM0/3D**

Further Mathematics

Advanced

PAPER 3D: Decision Mathematics 1

You must have:
Mathematical Formulae and Statistical Tables (Green), calculator,
Decision Mathematics Answer Book (enclosed)

Candidates may use any calculator permitted by Pearson regulations. Calculators must not have the facility for symbolic algebra manipulation, differentiation and integration, or have retrievable mathematical formulae stored in them.

Instructions

- Use **black** ink or ball-point pen.
- If pencil is used for diagrams/sketches/graphs it must be dark (HB or B).
- Write your answers for this paper in the Decision Mathematics answer book provided.
- **Fill in the boxes** at the top of the answer book with your name, centre number and candidate number.
- Do not return the question paper with the answer book
- Answer **all** questions and ensure that your answers to parts of questions are clearly labelled.
- Answer the questions in the answer book provided
  – *there may be more space than you need.*
- You should show sufficient working to make your methods clear. Answers without working may not gain full credit.
- Inexact answers should be given to three significant figures unless otherwise stated.

Information

- A booklet 'Mathematical Formulae and Statistical Tables' is provided.
- There are 7 questions in this question paper. The total mark for this paper is 75.
- The marks for **each** question are shown in brackets
  – *use this as a guide as to how much time to spend on each question.*

Advice

- Read each question carefully before you start to answer it.
- Try to answer every question.
- Check your answers if you have time at the end.

Turn over ▶

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1.

4.7 2.9 5.5 1.4 5.8 2.8 3.8 6.5 5.1 6.3 4.1

(a) Use the first-fit bin packing algorithm to determine how the numbers listed above can be packed into bins of size 13

(3)

(b) Use the first-fit decreasing bin packing algorithm to determine how the numbers listed above can be packed into bins of size 13

(2)

(Total for Question 1 is 5 marks)

2.

271 828 182 845 904 523 536 028 747 135

The list of ten numbers above is to be sorted into descending order.

(a) Perform a quick sort on the list to obtain the sorted list. You should show the result of each pass and identify the pivots clearly.

(4)

A list of n numbers is to be sorted into descending order using bubble sort.

(b) Determine, in the worst case, the total number of comparisons required to sort the list. Give your answer as a simplified expression in terms of n.

(2)

The following algorithm determines an approximation to the value of e

Step 1 Start

Step 2 Let $a = 1$

Step 3 Let $b = 1$

Step 4 Let $c = 1$

Step 5 Let $d = a$

Step 6 Let $c = c \times b$

Step 7 Let $d = d + \frac{1}{c}$

Step 8 If $b = 6$ go to Step 11

Step 9 Let $b = b + 1$

Step 10 Go to Step 6

Step 11 Output d

Step 12 Stop

(c) Complete the table in the answer book to show the results obtained at each step of the algorithm.

(3)

(d) Calculate, to 3 significant figures, the percentage error in using the value found in (c) to approximate the value of e

(1)

(Total for Question 2 is 10 marks)

3.

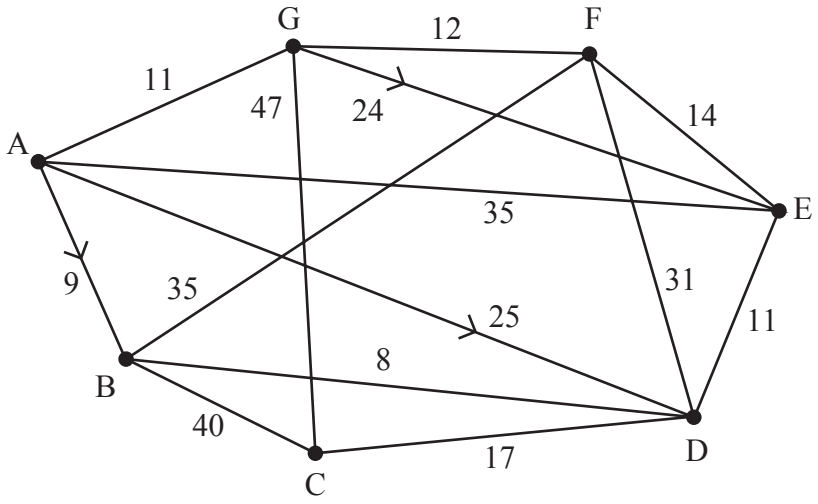


Figure 1

Direct roads between seven villages, A, B, C, D, E, F and G, are represented in Figure 1. The weight on each arc is the time, in minutes, taken to travel along the corresponding road. Three roads, AB, AD and GE, are one-way, as indicated by the arrow on the corresponding arc.

Floyd's algorithm is to be used to find the complete network of shortest times between the seven villages.

(a) Set up an initial time matrix for this network.

(2)

The time matrix after three iterations of Floyd's algorithm is shown below.

	A	**B**	**C**	**D**	**E**	**F**	**G**
A	–	9	49	17	35	44	11
B	∞	–	40	8	∞	35	87
C	∞	40	–	17	∞	75	47
D	∞	8	17	–	11	31	64
E	35	44	84	11	–	14	46
F	∞	35	75	31	14	–	12
G	11	20	47	28	24	12	–

(b) Perform the next two iterations of Floyd's algorithm that follow from the table above.

You should show only the time matrix after each iteration.

(5)

The final time matrix after completion of Floyd's algorithm is shown below.

	A	B	C	D	E	F	G
A	–	9	34	17	28	23	11
B	54	–	25	8	19	33	45
C	58	25	–	17	28	42	47
D	46	8	17	–	11	25	37
E	35	19	28	11	–	14	26
F	23	32	42	25	14	–	12
G	11	20	45	28	24	12	–

Albert must visit each village. He will start and finish at B and wishes to minimise the total time taken to visit each village.

(c) (i) Use the nearest neighbour algorithm, starting at B, to find a Hamiltonian cycle in the complete network of shortest times shown above.

(ii) Find the total travel time for this cycle.

(iii) Given that he travels the Hamiltonian cycle found in (c)(i), interpret this cycle in terms of the actual villages visited by Albert.

(3)

(Total for Question 3 is 10 marks)

4.

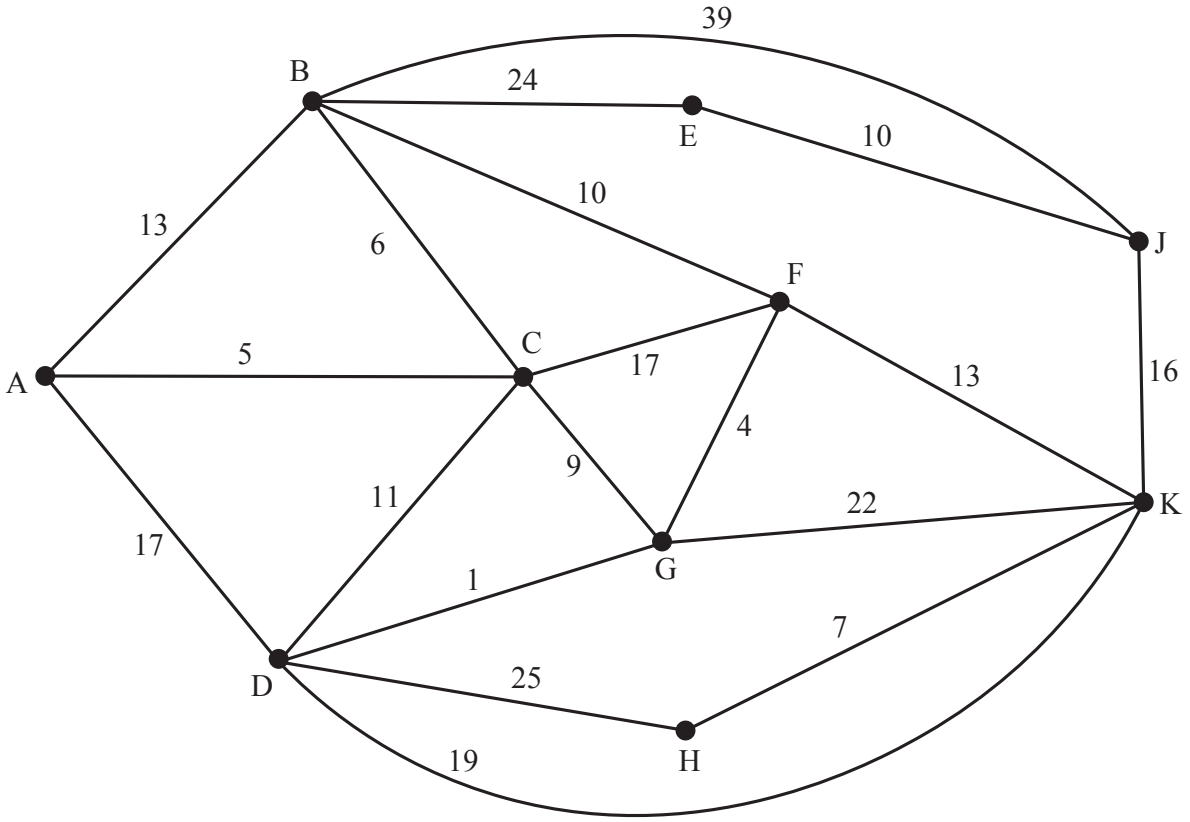


Figure 2

[*The total weight of the network is* 268]

Figure 2 represents a network of corridors between 10 offices, A, B, C, D, E, F, G, H, J and K, in a building. The number on each edge represents the length, in metres, of the corresponding corridor.

On Monday morning, Turvi needs to walk from J to K via A. She wishes to minimise the distance she travels along the corridors.

(a) (i) Use Dijkstra's algorithm, starting at A, to find the shortest route from J to K via A.

(ii) State the length of this route.

(6)

On Monday afternoon, Turvi needs a route that traverses each corridor at least once. She plans to start at J and finish at A and wants to minimise the distance travelled.

(b) (i) By considering the pairings of all relevant nodes, find the corridors that would need to be traversed twice. You must make your method and working clear.

(ii) State the total length of this route.

(5)

Turvi discovers that she cannot walk along corridors AB, CD and JK because they are being decorated. Turvi walks from J to A travelling along all the other corridors at least once. She does this in the minimum distance possible.

(c) Determine the difference between the length of the route Turvi travels and the length of the route found in (b). You must make the values used in your calculation clear.

(2)

(Total for Question 4 is 13 marks)

5. Consider the following linear programming problem in x, y and z.

Maximise $P = 3x + 4y + 2z$

subject to $2x + 2y + 2z \leqslant 21$

$2x - y - z \leqslant 18$

$-3x + y - 2z \leqslant 1$

$x \geqslant 4 \qquad y \geqslant 1 \qquad z \leqslant -3$

(a) Explain why the Simplex algorithm cannot be used to solve this linear programming problem in its current form.

(1)

(b) Use the substitutions $x = X + 4$, $y = Y + 1$, $z = -Z - 3$ and $P = Q + 10$ to reformulate the linear programming problem into a form in which the Simplex algorithm can be used to solve the problem. You should write the constraints as simplified inequalities with integer coefficients.

(3)

After a second iteration of the Simplex algorithm, a possible tableau T is

b.v.	X	Y	Z	s_1	s_2	s_3	Value
X	1	0	$-\frac{3}{4}$	$\frac{1}{8}$	0	$-\frac{1}{4}$	$\frac{5}{8}$
s_2	0	0	$\frac{9}{4}$	$\frac{1}{8}$	1	$\frac{3}{4}$	$\frac{117}{8}$
Y	0	1	$-\frac{1}{4}$	$\frac{3}{8}$	0	$\frac{1}{4}$	$\frac{63}{8}$
Q	0	0	$-\frac{5}{4}$	$\frac{15}{8}$	0	$\frac{1}{4}$	$\frac{267}{8}$

(c) Write down the profit equation given by T.

(1)

(d) Using your answer to (c), explain why T is not optimal.

(1)

(e) (i) Perform the third iteration of the Simplex algorithm. You should state the row operations you use.

(ii) Hence determine the maximum value of P, and the corresponding values of x, y and z.

(6)

(Total for Question 5 is 12 marks)

6.

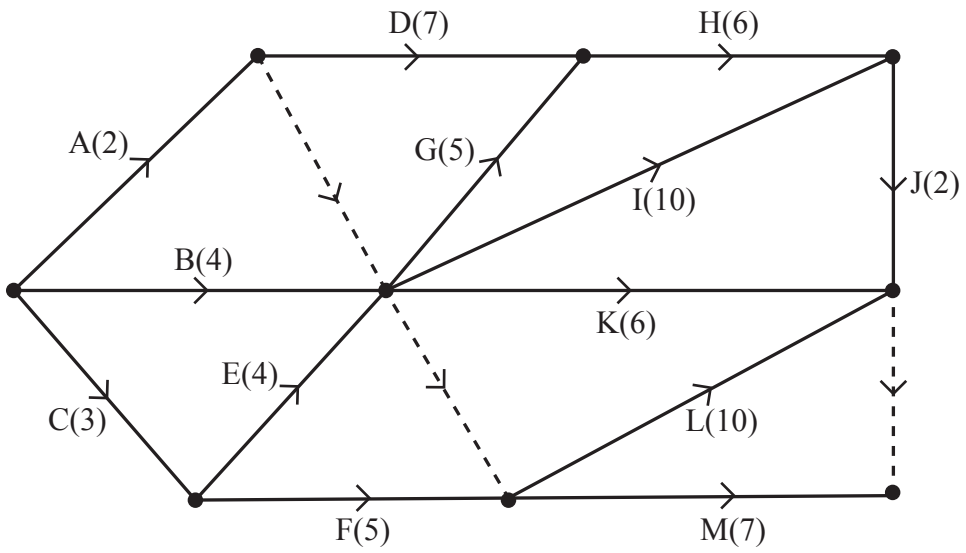


Figure 3

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 hours, to complete the corresponding activity. The project is to be completed in the shortest possible time.

(a) Complete Table 1 in the answer book to show the immediately preceding activities for each activity.

(2)

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

(4)

(c) Draw a Gantt chart for this project on Grid 1 in the answer book.

(4)

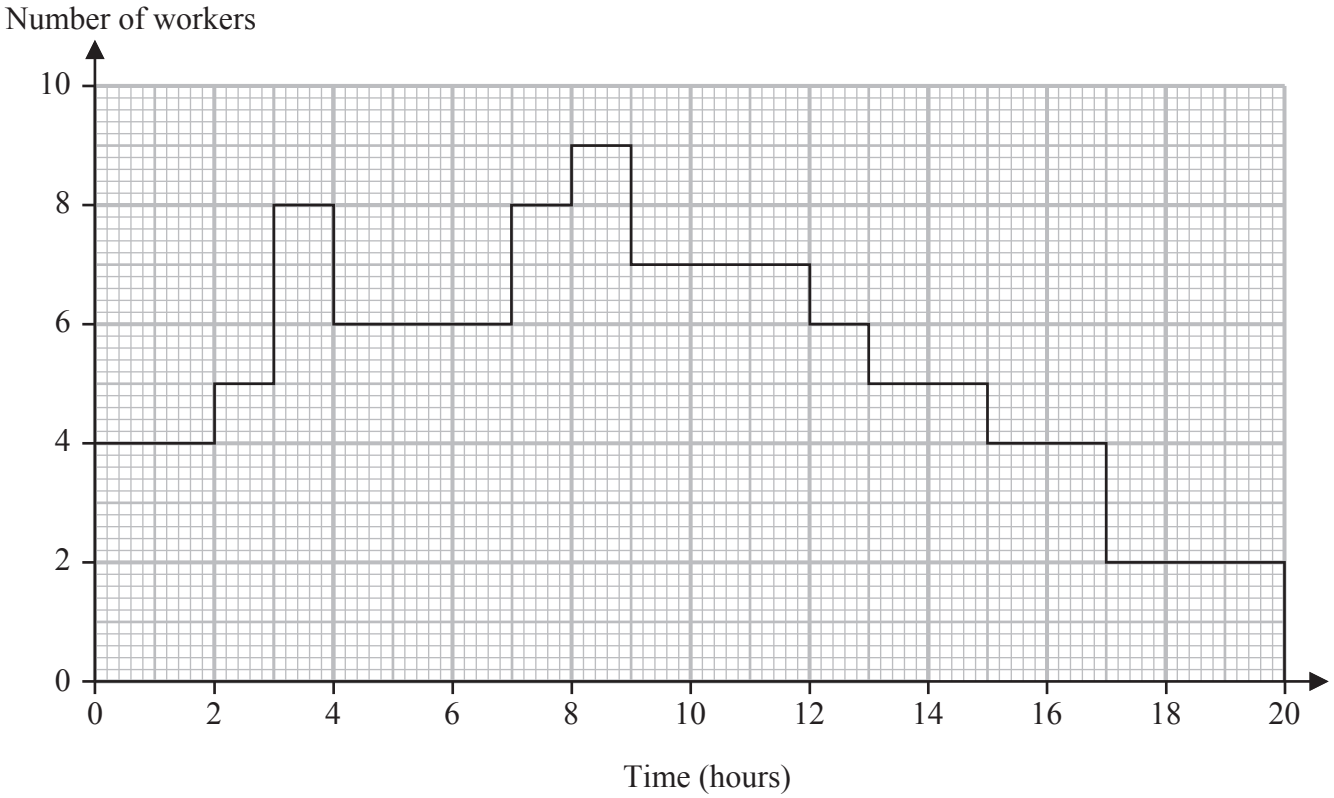


Figure 4

The resource histogram in Figure 4 shows the number of workers required when each activity starts at its earliest possible time. When an activity is started it must be completed without interruption. Each activity requires at least one worker.

(d) By considering which activities are happening each hour, and by working backwards from the minimum project completion time, complete Table 2 in the answer book to show the number of workers needed for each activity.

(3)

(Total for Question 6 is 13 marks)

7.

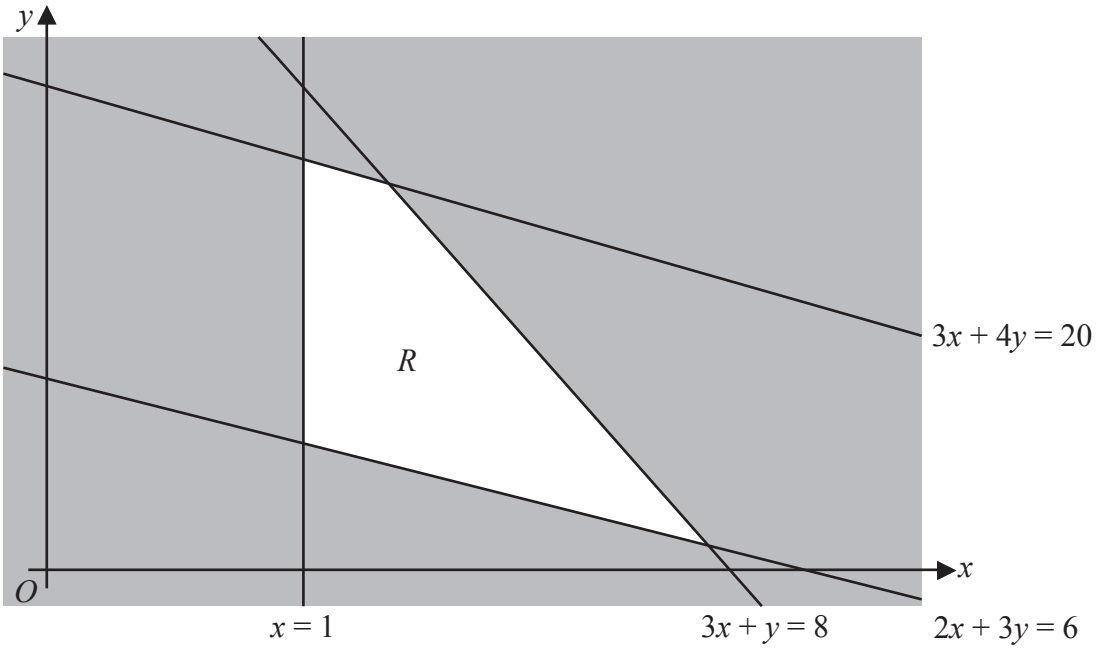


Figure 5

Figure 5 shows the constraints of a linear programming problem in x and y, where R is the feasible region.

The objective is to maximise $P = 11x + ky$, where k is a positive constant.

The optimal value of P is to be found using the big-M method.

(a) Set up an initial tableau for solving this linear programming problem using the big-M method.

You should use exactly 2 slack variables, 2 surplus variables and 2 artificial variables.

(7)

After a third iteration of the big-M method, a possible tableau is

b.v.	x	y	s_1	s_2	s_3	s_4	a_1	a_2	Value
s_1	0	0	1	0	$\frac{9}{7}$	$-\frac{1}{7}$	0	$-\frac{9}{7}$	$\frac{78}{7}$
x	1	0	0	0	$\frac{1}{7}$	$\frac{3}{7}$	0	$-\frac{1}{7}$	$\frac{18}{7}$
y	0	1	0	0	$-\frac{3}{7}$	$-\frac{2}{7}$	0	$\frac{3}{7}$	$\frac{2}{7}$
s_2	0	0	0	1	$\frac{1}{7}$	$\frac{3}{7}$	-1	$-\frac{1}{7}$	$\frac{11}{7}$
P	0	0	0	0	$\frac{11}{7}-\frac{3}{7}k$	$\frac{33}{7}-\frac{2}{7}k$	M	$M-\frac{11}{7}+\frac{3}{7}k$	$\frac{198}{7}+\frac{2}{7}k$

(b) Given that the third iteration gives the optimal value for P, determine this value.

(5)

(Total for Question 7 is 12 marks)

TOTAL FOR PAPER IS 75 MARKS

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Please check the examination details below before entering your candidate information

Candidate surname StemUp Model Solution | Other names

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Further Mathematics

Advanced

PAPER 3D: Decision Mathematics 1

Answer Book
Do not return the question paper with the answer book.

Total Marks

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1.

4.7 2.9 5.5 1.4 5.8 2.8 3.8 6.5 5.1 6.3 4.1

(a) First-fit, bins of size 13:

Bin 1: 4.7 2.9 1.4 2.8

Bin 2: 5.5 5.8

Bin 3: 3.8 6.5

Bin 4: 5.1 6.3

Bin 5: 4.1

(b) Sorted into decreasing order:

6.5 6.3 5.8 5.5 5.1 4.7 4.1 3.8 2.9 2.8 1.4

First-fit decreasing:

Bin 1: 6.5 6.3

Bin 2: 5.8 5.5 1.4

Bin 3: 5.1 4.7 2.9

Bin 4: 4.1 3.8 2.8

(Total for Question 1 is 5 marks)

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2.

271 828 182 845 904 523 536 028 747 135

(a) Quick sort (pivot = middle item, middle right if even), pivots ringed:

271	828	182	845	904	(523)	536	028	747	135	Pivot 523
828	845	(904)	536	747	523	271	182	(028)	135	Pivots 904, 028
904	828	845	(536)	747	523	271	(182)	135	028	Pivots 536, 182
904	828	(845)	747	536	523	271	182	135	028	Pivot 845
904	845	828	(747)	536	523	271	182	135	028	Pivot 747
904	845	828	747	536	523	271	182	135	028	

Sorted list: 904 845 828 747 536 523 271 182 135 028

(b) Worst case: the first pass makes $(n - 1)$ comparisons, the second $(n - 2)$, and so on down to 1 on the last pass.

Total $= (n - 1) + (n - 2) + \ldots + 2 + 1$

$= \frac{1}{2}n(n - 1)$

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Question 2 continued

You may not need to use all the rows in this table.

It may not be necessary to complete all boxes in each row.

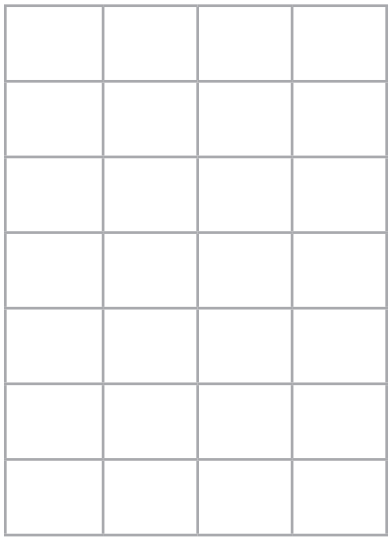
(c)

a	*b*	*c*	*d*
1	1	1	1
		1	2
	2	2	$\frac{5}{2}$
	3	6	$\frac{8}{3}$
	4	24	$\frac{65}{24}$
	5	120	$\frac{163}{60}$
	6	720	$\frac{1957}{720}$

Table continued on page 5.

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Question 2 continued



Output: d = 1957/720 (= 2.7180555...)

(d) e = 2.7182818284..., 1957/720 = 2.7180555556...

Error = 2.7182818284... − 2.7180555556... = 0.0002262728...

Percentage error = 0.0002262728... ÷ 2.7182818284... × 100

= 0.0083240... = 0.00832 %

(Total for Question 2 is 10 marks)

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3.

(a) **Initial time matrix**

	A	B	C	D	E	F	G
A	–	9	∞	25	35	∞	11
B	∞	–	40	8	∞	35	∞
C	∞	40	–	17	∞	∞	47
D	∞	8	17	–	11	31	∞
E	35	∞	∞	11	–	14	∞
F	∞	35	∞	31	14	–	12
G	11	∞	47	∞	24	12	–

(b) **Fourth iteration**

	A	B	C	D	E	F	G
A	–	9	34	17	28	44	11
B	∞	–	25	8	19	35	72
C	∞	25	–	17	28	48	47
D	∞	8	17	–	11	31	64
E	35	19	28	11	–	14	46
F	∞	35	48	31	14	–	12
G	11	20	45	28	24	12	–

Fifth iteration

	A	B	C	D	E	F	G
A	–	9	34	17	28	42	11
B	54	–	25	8	19	33	65
C	63	25	–	17	28	42	47
D	46	8	17	–	11	25	57
E	35	19	28	11	–	14	46
F	49	33	42	25	14	–	12
G	11	20	45	28	24	12	–

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Question 3 continued

(c)(i) Nearest neighbour starting at B:

B – D – E – F – G – A – C – B

(BD 8, DE 11, EF 14, FG 12, GA 11, AC 34, CB 25)

(ii) Total time = 8 + 11 + 14 + 12 + 11 + 34 + 25 = 115 minutes

(iii) A to C (34) is A – B – D – C and C to B (25) is C – D – B,

so the actual villages visited are

B D E F G A B D C D B

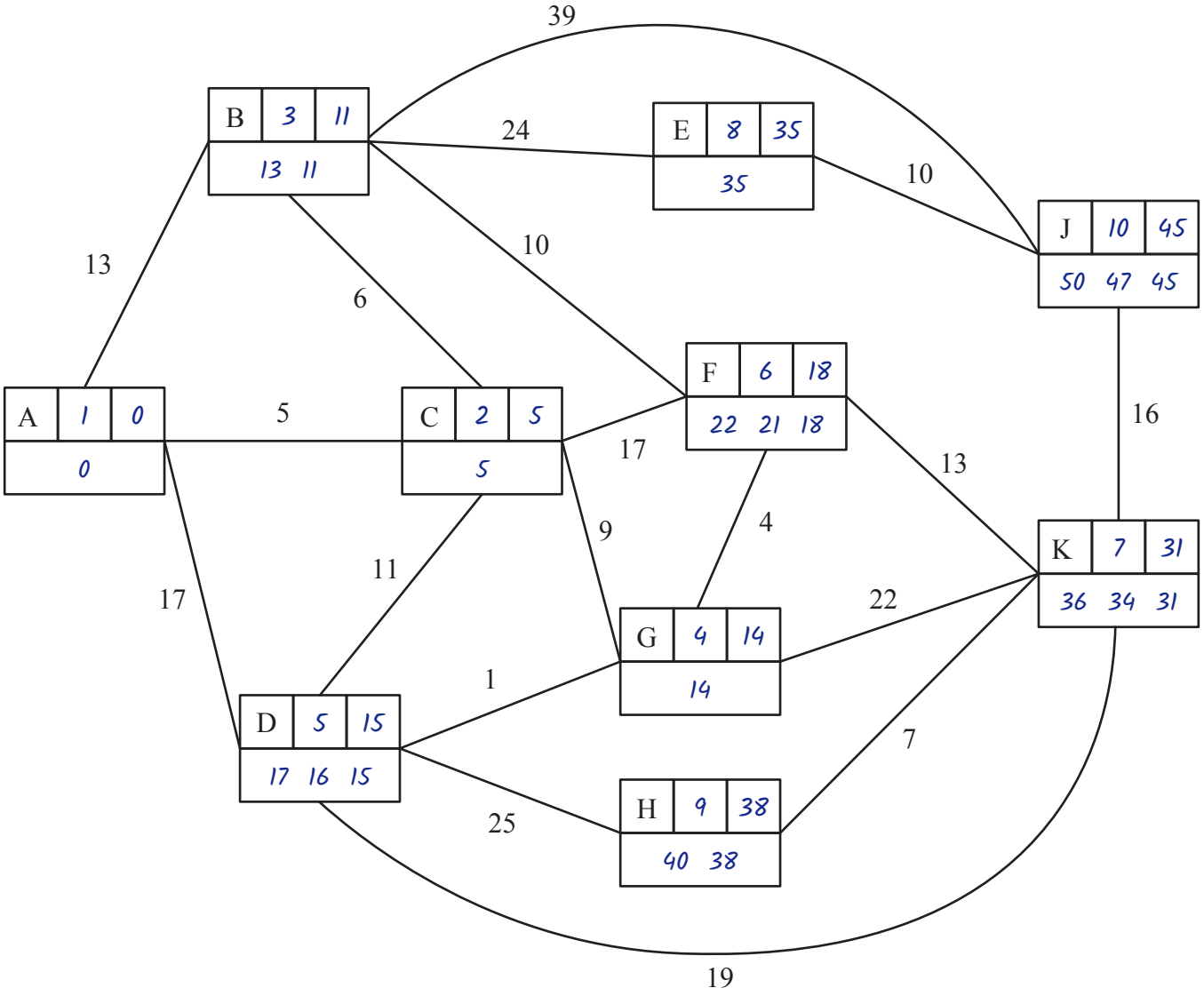
(Total for Question 3 is 10 marks)

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4.



Key:

Vertex	Order of labelling	Final value
Working value		

Shortest route from J to K via A: J – E – B – C – A – C – G – F – K

Length of shortest route from J to K via A: 45 + 31 = 76 m

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Question 4 continued

(b)(i) Odd nodes: A, B, C, D, J and K. The route starts at J and finishes at A, so pair the remaining odd nodes B, C, D and K:

BC + DK = 6 + 18 = 24 (DK via D G F K)

BD + CK = 15 + 26 = 41 (BD via B F G D, CK via C G F K)

BK + CD = 23 + 10 = 33 (BK via B F K, CD via C G D)

Least is 24, so the corridors traversed twice are BC, DG, GF and FK

(ii) Length of route = 268 + 24 = 292 m

(c) Without AB, CD and JK: 268 − (13 + 11 + 16) = 268 − 40 = 228

Removing these corridors makes every node even, so to start at J and finish at A the shortest path from J to A must be repeated:

J − E − B − C − A = 45 (from (a), uses none of the closed corridors)

Length of Turvi's route = 228 + 45 = 273 m

Difference = 292 − 273 = 19 m

Question 4 continued

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Question 4 continued

(Total for Question 4 is 13 marks)

5.

(a) The origin is not in the feasible region (e.g. $x \geqslant 4$, $z \leqslant -3$), so there is no obvious initial basic feasible solution; Simplex needs all variables to be non-negative.

(b) $2(X + 4) + 2(Y + 1) + 2(-Z - 3) \leqslant 21 \Rightarrow 2X + 2Y - 2Z \leqslant 17$

$2(X + 4) - (Y + 1) - (-Z - 3) \leqslant 18 \Rightarrow 2X - Y + Z \leqslant 8$

$-3(X + 4) + (Y + 1) - 2(-Z - 3) \leqslant 1 \Rightarrow -3X + Y + 2Z \leqslant 6$

$Q + 10 = 3(X + 4) + 4(Y + 1) + 2(-Z - 3) \Rightarrow Q = 3X + 4Y - 2Z$

Maximise $Q = 3X + 4Y - 2Z$, with $X \geqslant 0$, $Y \geqslant 0$, $Z \geqslant 0$

(c) $Q - \frac{5}{4}Z + \frac{15}{8}s_1 + \frac{1}{4}s_3 = \frac{267}{8}$

(d) $Q = \frac{267}{8} + \frac{5}{4}Z - \frac{15}{8}s_1 - \frac{1}{4}s_3$

Z has a positive coefficient, so increasing Z (from 0) increases Q, hence T is not optimal.

(e)(i) Pivot column Z (most negative, $-5/4$ in the Q row)

Only positive entry in the Z column is in the s_2 row:

$\theta = \frac{117}{8} \div \frac{9}{4} = \frac{13}{2}$, so the pivot is $\frac{9}{4}$ in the s_2 row

Z enters, s_2 leaves. Third tableau on the next page.

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Question 5 continued

(e) (i)

b.v.	X	Y	Z	s_1	s_2	s_3	Value
X	1	0	$-\frac{3}{4}$	$\frac{1}{8}$	0	$-\frac{1}{4}$	$\frac{5}{8}$
s_2	0	0	$\frac{9}{4}$	$\frac{1}{8}$	1	$\frac{3}{4}$	$\frac{117}{8}$
Y	0	1	$-\frac{1}{4}$	$\frac{3}{8}$	0	$\frac{1}{4}$	$\frac{63}{8}$
Q	0	0	$-\frac{5}{4}$	$\frac{15}{8}$	0	$\frac{1}{4}$	$\frac{267}{8}$

b.v.	X	Y	Z	s_1	s_2	s_3	Value	Row Ops
X	1	0	0	$\frac{1}{6}$	$\frac{1}{3}$	0	$\frac{11}{2}$	$r_1 + \frac{3}{4} R_2$
z	0	0	1	$\frac{1}{18}$	$\frac{4}{9}$	$\frac{1}{3}$	$\frac{13}{2}$	$R_2 = \frac{4}{9} r_2$
Y	0	1	0	$\frac{7}{18}$	$\frac{1}{9}$	$\frac{1}{3}$	$\frac{19}{2}$	$r_3 + \frac{1}{4} R_2$
Q	0	0	0	$\frac{35}{18}$	$\frac{5}{9}$	$\frac{2}{3}$	$\frac{83}{2}$	$r_4 + \frac{5}{4} R_2$

(e)(ii)

No negative values in the Q row, so this tableau is optimal:

$X = 5.5$, $Y = 9.5$, $z = 6.5$, $Q = 41.5$

$x = X + 4 = 9.5$, $y = Y + 1 = 10.5$, $z = -z - 3 = -9.5$

Maximum $P = Q + 10 = 51.5$ $(= 103/2)$

when $x = 9.5$, $y = 10.5$, $z = -9.5$

(Total for Question 5 is 12 marks)

6. (a)

Activity	Immediately preceding activities
A	–
B	–
C	–
D	A
E	C
F	C

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

Table 1

Key:

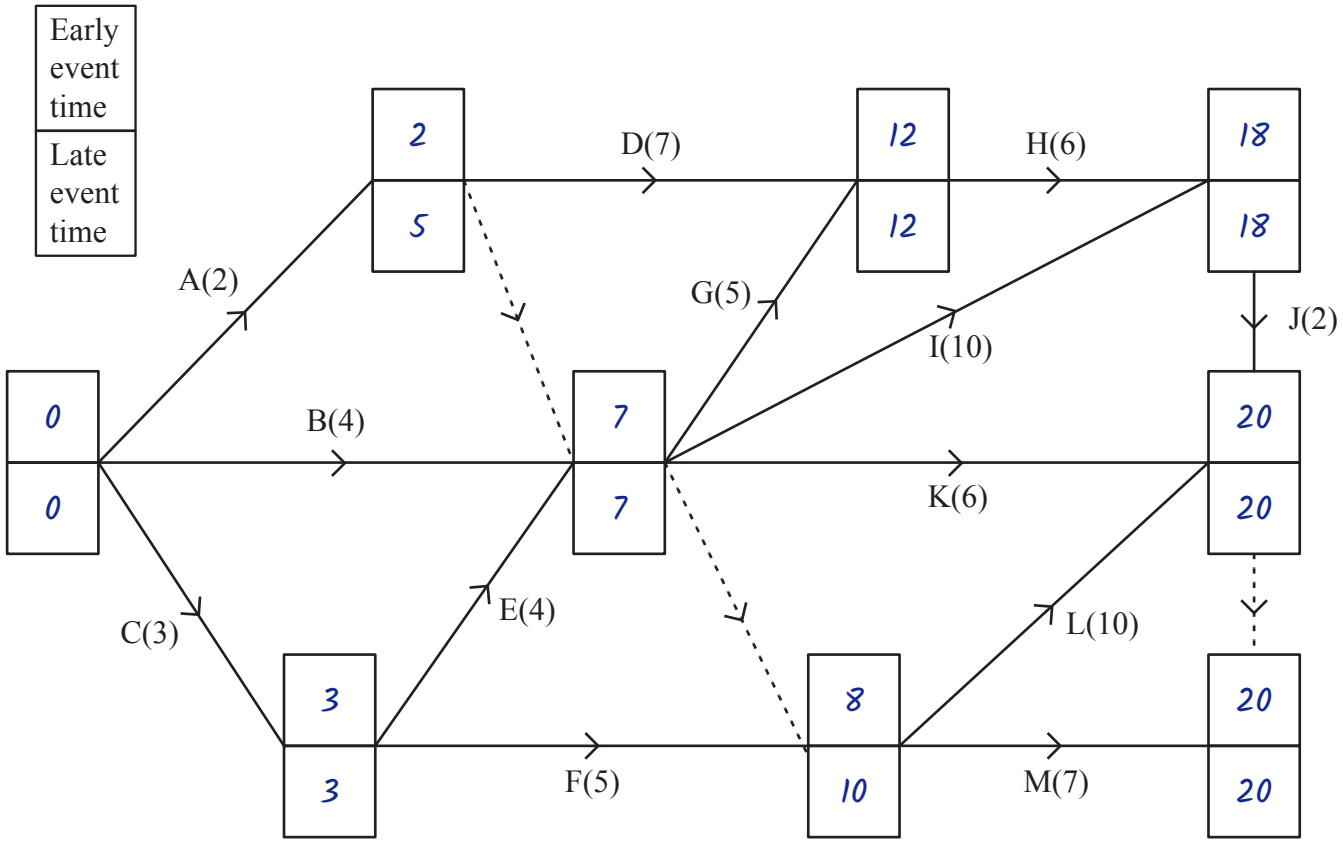


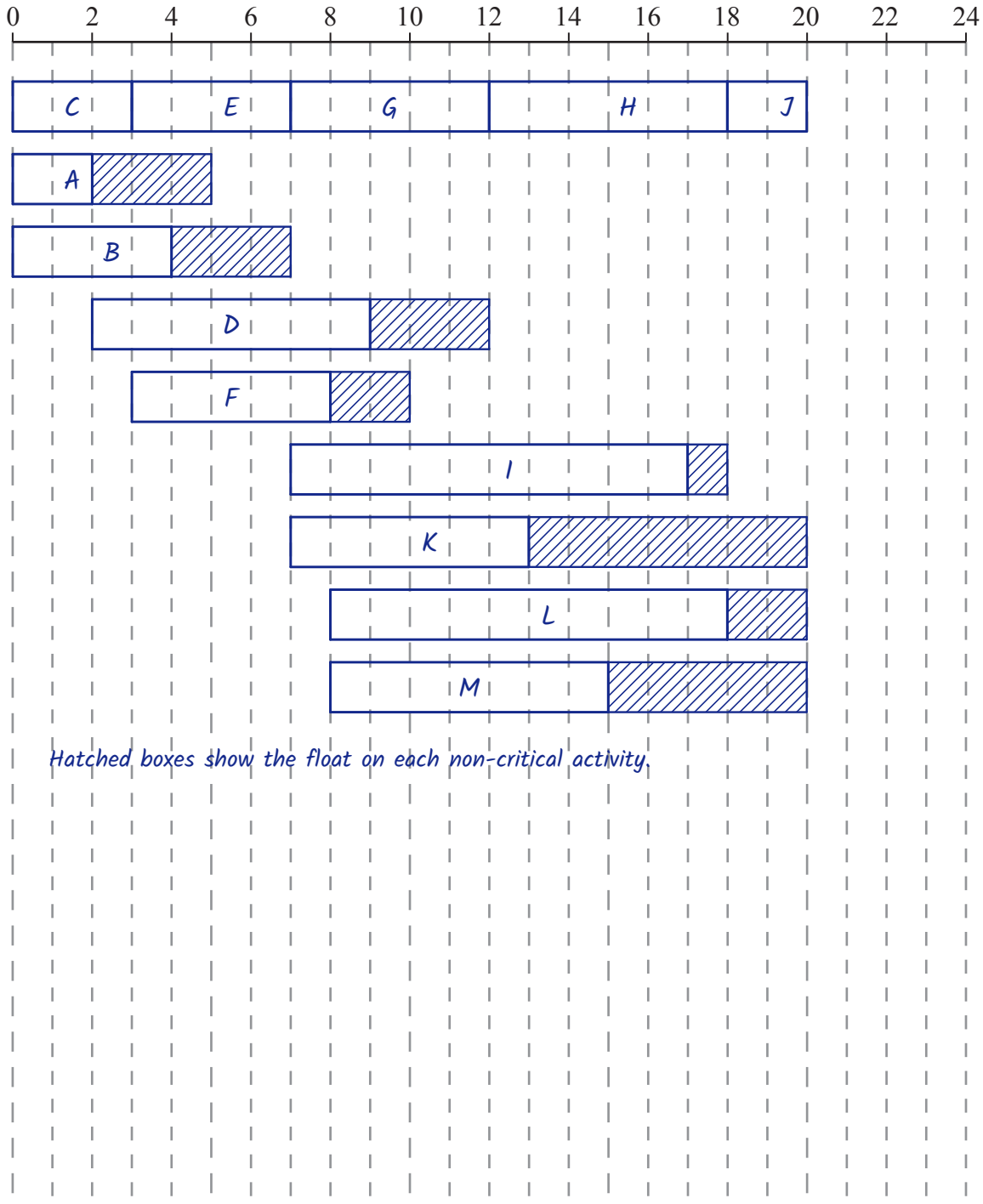
Diagram 1

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Question 6 continued

(c)



Grid 1

Question 6 continued

(d)

You may use the following resource histogram for working.

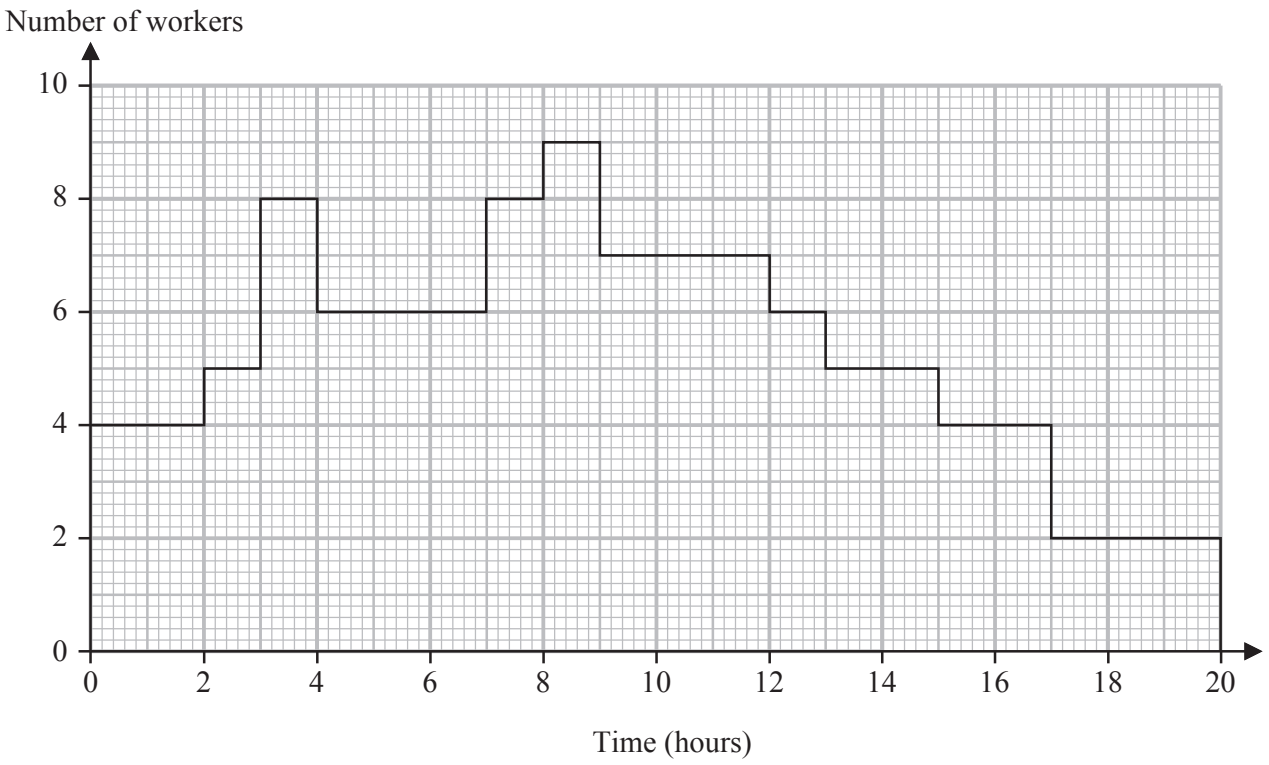


Figure 4

17–18: H, L = 2 ⇒ H = 1, L = 1; 18–20: J = 2; 15–17: H, I, L = 4 ⇒ I = 2;

13–15: M = 1; 12–13: K = 1; 9–12: G = 2; 8–9: D = 2; 7–8: F = 1;

4–7: E = 3; 3–4: B = 2; 2–3: C = 1; 0–2: A = 1

Activity	Number of Workers
A	1
B	2
C	1
D	2
E	3
F	1

Activity	Number of Workers
G	2
H	1
I	2
J	2
K	1
L	1
M	1

Table 2

(Total for Question 6 is 13 marks)

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7.

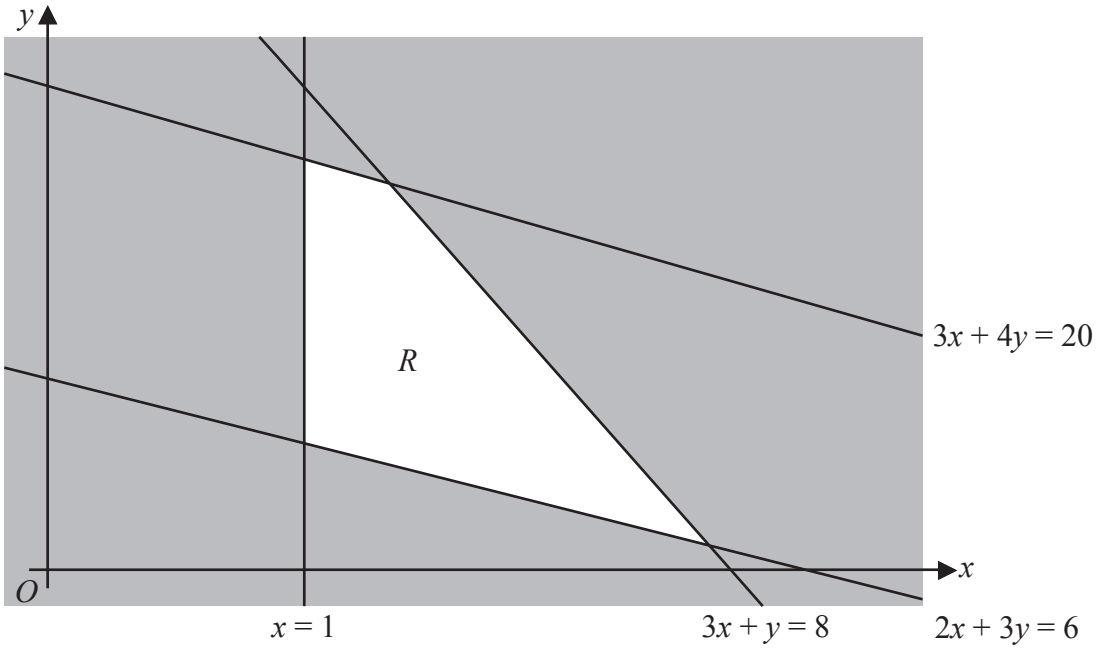


Figure 5

(a) $3x + 4y \leqslant 20 \Rightarrow 3x + 4y + s_1 = 20$

$3x + y \leqslant 8 \Rightarrow 3x + y + s_4 = 8$

$x \geqslant 1 \Rightarrow x - s_2 + a_1 = 1$

$2x + 3y \geqslant 6 \Rightarrow 2x + 3y - s_3 + a_2 = 6$

$P = 11x + ky - M(a_1 + a_2)$

$a_1 + a_2 = (1 - x + s_2) + (6 - 2x - 3y + s_3)$

$= 7 - 3x - 3y + s_2 + s_3$

$P = 11x + ky - M(7 - 3x - 3y + s_2 + s_3)$

$P = (11 + 3M)x + (k + 3M)y - Ms_2 - Ms_3 - 7M$

$\Rightarrow P - (11 + 3M)x - (k + 3M)y + Ms_2 + Ms_3 = -7M$

Initial tableau: see the table on the next page.

The tableau can be found at the bottom of page 18.

Question 7 continued

b.v.	x	y	s_1	s_2	s_3	s_4	a_1	a_2	Value
s_1	3	4	1	0	0	0	0	0	20
a_1	1	0	0	−1	0	0	1	0	1
a_2	2	3	0	0	−1	0	0	1	6
s_4	3	1	0	0	0	1	0	0	8
P	$-(11 + 3M)$	$-(k + 3M)$	0	M	M	0	0	0	$-7M$

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Question 7 continued

(b) From the tableau, $x = \frac{18}{7}$ and $y = \frac{2}{7}$

$P = 11 \times \frac{18}{7} + k \times \frac{2}{7} = \frac{198}{7} + \frac{2}{7}k$

Optimal, so no negative entries in the P row:

s_3 column: $\frac{11}{7} - \frac{3}{7}k \geq 0 \quad \Rightarrow \quad k \leq \frac{11}{3}$

s_4 column: $\frac{33}{7} - \frac{2}{7}k \geq 0 \quad \Rightarrow \quad k \leq \frac{33}{2}$

(a_2 column: M is very large, so this entry is positive)

Hence $0 < k \leq \frac{11}{3}$

P is greatest when $k = \frac{11}{3}$: $P = \frac{198}{7} + \frac{2}{7} \times \frac{11}{3} = \frac{88}{3}$

So the optimal value is $P = \frac{198}{7} + \frac{2}{7}k$, where $\frac{198}{7} < P \leq \frac{88}{3}$,

with maximum value $P = \frac{88}{3}$ (when $k = \frac{11}{3}$)

Question 7 continued

(Total for Question 7 is 12 marks)

TOTAL FOR PAPER IS 75 MARKS

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