

**Paper 4G: Decision Mathematics 2 Mark Scheme**

Question	Scheme	Marks	AOs
<b>1(a)</b>	Auxiliary equation: $\lambda^2 - \lambda - 1 = 0$ and attempt to solve	M1	1.1b
	$\lambda = \frac{1 \pm \sqrt{5}}{2} \Rightarrow u_n = A \left( \frac{1 + \sqrt{5}}{2} \right)^n + B \left( \frac{1 - \sqrt{5}}{2} \right)^n$ , where $A$ and $B$ are arbitrary constants	M1 A1	1.1b 2.2a
		<b>(3)</b>	
<b>(b)</b>	Use given conditions to obtain two equations in $A$ and $B$	M1	1.1b
	Attempt to solve to obtain an $A$ and $B$	M1	1.1b
	$u_n = \frac{1}{\sqrt{5}} \left\{ \left( \frac{1 + \sqrt{5}}{2} \right)^n - \left( \frac{1 - \sqrt{5}}{2} \right)^n \right\}$	A1	1.1b
		<b>(3)</b>	
<b>(6 marks)</b>			
<b>Notes:</b>			
<p><b>(a)</b></p> <p><b>M1:</b> writes down correct auxiliary equation and attempts to solve using either the formula or completing the square</p> <p><b>M1:</b> writes down the general solution in the form <math>u_n = A(\lambda_1)^n + B(\lambda_2)^n</math> using their roots <math>\lambda_1, \lambda_2</math> - dependent on the first M mark</p> <p><b>A1:</b> CAO – both lhs and rhs correct including defining <math>A</math> and <math>B</math> as (arbitrary) constants</p>			
<p><b>(b)</b></p> <p><b>M1:</b> uses the correct initial conditions to write down two equations in <math>A</math> and <math>B</math> – for reference these equations are <math>A(1 + \sqrt{5}) + B(1 - \sqrt{5}) = 2</math> and <math>A(1 + \sqrt{5})^2 + B(1 - \sqrt{5})^2 = 4</math></p> <p><b>M1:</b> Attempts to solve these two equations (using a correct method but condone sign slips) to achieve a value for <math>A</math> and <math>B</math></p> <p><b>A1:</b> CAO</p>			

Question	Scheme						Marks	AOs	
2(a)			D	E	F	Available			
	A		25			25			
	B		13	24	18	55			
	C				20	20			
	Required		38	24	38				
							(1)		
(b)		Shadow costs		15	22	14		M1	2.1
				D	E	F			
	0	A	X	-3	-5				
	-4	B	X	X	X			A1	1.1b
	4	C	-8	-14	X				
			D	E	F			M1	2.1
	A								
	B		24 - θ	18 + θ				A1	1.1b
	C		θ	20 - θ					
	Entering CE, exiting CF								
	Shadow costs		15	22	14		M1	1.1b	
			D	E	F				
0	A	X	-3	-5					
-4	B	X	X	X			A1	1.1b	
-10	C	6	X	14					
		D	E	F			M1	1.1b	
A	25 - θ		θ						
B	13 + θ		38 - θ						
C							A1	2.2a	
Entering AF, exiting AD									
	Shadow costs		10	17	9		M1	2.1	
			D	E	F				
0	A	5	2	X					
1	B	X	X	X			A1	1.1b	
-5	C	6	X	14					
No negative IIs so optimal solution of £1085							A1	2.4	
							(11)		
(12 marks)									

**Notes:**

**B1:** CAO

**M1:** Finding all 6 shadow costs and the 4 improvement indices for the correct 4 entries – candidates must clearly identify these two sets of results

**A1:** Shadow costs and II CAO

**M1:** A valid route, their most negative II chosen, only one empty square used,  $\theta$ 's balance

**A1:** CAO

**M1:** Finding all 6 shadow costs and the 4 improvement indices for the correct 4 entries

**A1:** Shadow costs and II CAO

**M1:** A valid route, their most negative II chosen, only one empty square used,  $\theta$ 's balance

**A1:** CAO – including the deduction of all entering and exiting cells

**M1:** Finding all 6 shadow costs and the 4 improvement indices for the correct 4 entries – this mark is dependent on all previous M marks which will therefore indicate a correct mathematical argument leading from the initial solution to the confirmation of the optimal solution

**A1:** Shadow costs and II CAO

**A1:** CSO including the correct reasoning that the solution is optimal because there are no negative IIs

Question	Scheme	Marks	AOs
<b>3(a)</b>	Subtract each entry from a constant (eg 40)	B1	2.4
		<b>(1)</b>	
<b>(b)</b>	<p>e.g. <math display="block">\begin{pmatrix} &amp; P &amp; Q &amp; R &amp; S \\ A &amp; 5 &amp; 5 &amp; 4 &amp; 2 \\ B &amp; 9 &amp; 2 &amp; 6 &amp; 0 \\ C &amp; 2 &amp; 8 &amp; 4 &amp; 1 \\ D &amp; 1 &amp; 7 &amp; 1 &amp; 4 \end{pmatrix}</math></p> <p>Reducing row A by 2, no reduction for row B, reduce row C by 1 and row D by 1. No reduction of columns P, R and S, reduce column Q by 2.</p> <p><math display="block">\begin{pmatrix} &amp; P &amp; Q &amp; R &amp; S \\ A &amp; 3 &amp; 3 &amp; 2 &amp; 0 \\ B &amp; 9 &amp; 2 &amp; 6 &amp; 0 \\ C &amp; 1 &amp; 7 &amp; 3 &amp; 0 \\ D &amp; 0 &amp; 6 &amp; 0 &amp; 3 \end{pmatrix}</math> then <math display="block">\begin{pmatrix} &amp; P &amp; Q &amp; R &amp; S \\ A &amp; 3 &amp; 1 &amp; 2 &amp; 0 \\ B &amp; 9 &amp; 0 &amp; 6 &amp; 0 \\ C &amp; 1 &amp; 5 &amp; 3 &amp; 0 \\ D &amp; 0 &amp; 4 &amp; 0 &amp; 3 \end{pmatrix}</math></p> <p>Three lines required to cover the zeros hence solution is not optimal – augment by 1</p> <p><math display="block">\begin{pmatrix} &amp; P &amp; Q &amp; R &amp; S \\ A &amp; 2 &amp; 1 &amp; 1 &amp; 0 \\ B &amp; 8 &amp; 0 &amp; 5 &amp; 0 \\ C &amp; 0 &amp; 5 &amp; 2 &amp; 0 \\ D &amp; 0 &amp; 5 &amp; 0 &amp; 4 \end{pmatrix}</math></p> <p>A – S, B – Q, C – P, D – R</p>	<p>B1</p> <p>B1</p> <p>M1</p> <p>A1</p> <p>B1</p> <p>M1</p> <p>A1</p>	<p>1.1b</p> <p>2.4</p> <p>2.1</p> <p>1.1b</p> <p>2.4</p> <p>2.1</p> <p>2.2a</p>
		<b>(7)</b>	
<b>(c)</b>	<p><math display="block">x_{ij} = \begin{cases} 1 &amp; \text{if worker } i \text{ does task } j \\ 0 &amp; \text{otherwise} \end{cases}</math></p> <p>Where <math>i \in \{A, B, C, D\}</math> and <math>j \in \{P, Q, R, S\}</math></p> <p>e.g. Minimise</p> $5x_{AP} + 5x_{AQ} + 4x_{AR} + 2x_{AS} + 9x_{BP} + 2x_{BQ} + 6x_{BR} + 2x_{CP} + 8x_{CQ} + 4x_{CR} + x_{CS} + x_{DP} + 7x_{DQ} + x_{DR} + 4x_{DS}$ <p>Subject to:</p> $\sum x_{iP} = 1, \sum x_{iQ} = 1, \sum x_{iR} = 1, \sum x_{iS} = 1$ $\sum x_{Aj} = 1, \sum x_{Bj} = 1, \sum x_{Cj} = 1, \sum x_{Dj} = 1$	<p>B1</p> <p>B1</p> <p>B1</p> <p>M1</p> <p>A1</p>	<p>3.3</p> <p>3.3</p> <p>3.3</p> <p>3.3</p> <p>3.3</p>
		<b>(5)</b>	
<b>(13 marks)</b>			

<b>Notes:</b>	
<b>(a)</b>	
<b>B1:</b>	valid statement regarding converting a max. problem to a min. problem
<b>(b)</b>	
<b>B1:</b>	CAO
<b>B1:</b>	Correct statements regarding row and column reduction
<b>M1:</b>	Simplifying the initial matrix by reducing rows <b>and then</b> columns
<b>A1:</b>	CAO
<b>B1:</b>	Correct statements regarding both max. number of lines to cover zeros and augmentation
<b>M1:</b>	Develop an improved solution – need to see one double covered +e; one uncovered –e; and one single covered unchanged. 3 lines needed to 4 lines needed (so getting to the optimal table)
<b>A1:</b>	CSO on final table (so must have scored all previous marks in this part ) + deduction of the correct allocation
<b>(c)</b>	
<b>B1:</b>	possible values of $x_{ij}$ defined
<b>B1:</b>	define the set of values for $i$ and $j$
<b>B1:</b>	Correct objective function and either ‘minimise’ or ‘maximise’ (dependent on if problem is defined in terms of original values or modified values)
<b>M1:</b>	at least four equations, unit coefficient and equal to 1
<b>A1:</b>	CAO (all eight equations)

Question	Scheme	Marks	AOs
<b>4(a)</b>		M1	3.3
		A1	1.1b
		M1	3.4
		A1	1.1b
		M1	3.4
		A1	1.1b
		<b>(6)</b>	
<b>(b)</b>	EMV is 1.48 (tokens) per game (correct to 3 sf)	B1	3.4
	Analysis: Play the game and if the player doesn't pick a 2 – 6 on the first go then they should pick again	B1	3.2a
		<b>(2)</b>	
<b>(8 marks)</b>			
<b>Notes:</b>			
<b>(a)</b> <b>M1:</b> Tree diagram with at least three end pay-offs, two decision nodes and two chance nodes <b>A1:</b> Correct structure of tree diagram with each arc labelled correctly (including probabilities) <b>M1:</b> At least three end-pay offs consistent with their stated probabilities; all five attempted <b>A1:</b> CAO for end-pay offs <b>M1:</b> End chance node follow through their end pay-offs and other chance/decision nodes completed <b>A1:</b> CAO for decision and chance nodes including double lines through inferior options			
<b>(b)</b> <b>B1:</b> Correct EMV <b>B1:</b> Correct analysis			

Question	Scheme	Marks	AOs
<b>5(a)</b>	Column 2 <u>dominates</u> column 4	B1	2.5
	Because $2 > -2, 0 > -1$ and $3 > 2$	B1	2.4
		<b>(2)</b>	
<b>(b)</b>	Row minima: -2, -1, -1 max is -1 Column maxima: 4, 2, 3 min is 2	M1 A1	1.1b 1.1b
	Play safe is A plays 2 or 3 and B plays 2	A1	1.1b
	Row maximin (-1) $\neq$ Column minimax (2) so not stable	A1	2.4
		<b>(4)</b>	
<b>(c)</b>	e.g. $\begin{pmatrix} 4 & -2 & 3 \\ 3 & -1 & 2 \\ -1 & 2 & 0 \end{pmatrix} \rightarrow \begin{pmatrix} 6 & 0 & 5 \\ 5 & 1 & 4 \\ 1 & 4 & 2 \end{pmatrix}$	B1	1.1b
	Subject to $V - 6p_1 - 5p_2 - p_3 \leq 0$	B1	3.3
	$V - p_2 - 4p_3 \leq 0$	B1	3.3
	$V - 5p_1 - 4p_2 - 2p_3 \leq 0$		
		<b>(3)</b>	
<b>(d)</b>	Substitute $p$ values to obtain $V \leq \frac{19}{7}, \frac{19}{7}, \frac{20}{7} \therefore V = \frac{19}{7}$	M1	3.4
	Value of the game to player A = $\frac{19}{7} - 2 = \frac{5}{7}$	M1 A1	1.1b 1.1b
		<b>(3)</b>	
<b>(12 marks)</b>			
<b>Notes:</b>			
<b>(a)</b>			
<b>B1:</b> Correct statement – must include the word ‘dominate’			
<b>B1:</b> Correct inequalities – must be clear that all three inequalities must hold			
<b>(b)</b>			
<b>M1:</b> Attempt at row minima and column maxima – condone one error			
<b>A1:</b> Correct max(row min) and min(col max)			
<b>A1:</b> Correct play safe for both players			
<b>A1:</b> Correct reasoning that the game is not stable (accept $-1 \neq 2$ + statement)			
<b>(c)</b>			
<b>B1:</b> Correct augmentation to make all entries non-negative			
<b>B1:</b> At least one (of the three) equations <b>or</b> inequalities correct in $V, p_1, p_2, p_3$ (with all $p_i$ terms in the constraint equations having correct signs)			
<b>B1:</b> CAO - all three constraints correct involving $V$ and $p_i$ expressed as inequalities			
<b>(d)</b>			
<b>M1:</b> Substitute $p$ values to obtain three values for $V$			
<b>M1:</b> Their least value of $V$ minus their augmented value			
<b>A1:</b> CAO for the value of the game to player A			

Question	Scheme	Marks	AOs
<b>6(a)</b>	$C_1 = 3 + 3 + 3 + 5 + 7 = 21$	B1	1.1b
	$C_2 = 8 + 5 + 3 + 6 - 3 = 19$	B1	1.1b
		(2)	
<b>(b)</b>	e.g. the minimum flow out of the source S is at least $5 + 3 + 4 = 12$ and the maximum flow into the sink T is $6 + 10 = 16$	B1	2.4
		(1)	
<b>(c)</b>	The minimum flow into G is $1 + 1 + 1 + 3 = 6$ but the maximum flow out of G is 6 therefore the arcs into G must be at their lower capacities	B1	2.4
		(1)	
<b>(d)</b>		M1 A1	3.1a 1.1b
		(2)	
<b>(e)</b>	Maximum flow is 15	B1	1.1b
	The minimum flow out of the source is 12 but the flow out of C is at least $3 + 4 = 7$	B1	2.4
	Therefore the minimum flow through the network is $5 + 3 + 3 + 4 = 15$ which is equal to the maximum flow	B1	2.2a
		(3)	
<b>(f)</b>	Increase the upper capacity of arc BF to at least 9 and therefore increase the flow in this arc to 9	B1	2.1
	Therefore increase the flow in FH and HT to 10	B1	2.4
	The flow in GT decreases to 5 and all other arcs are unchanged	B1	2.2a
		(3)	
(12 marks)			



<b>Notes:</b>	
<b>(a)</b>	<p><b>B1:</b> correct capacity for <math>C_1</math></p> <p><b>B1:</b> correct capacity for <math>C_2</math></p>
<b>(b)</b>	<b>B1:</b> correct statement regarding the min. flow out of the sink and max. flow into the sink
<b>(c)</b>	<b>B1:</b> correct statement regarding the flow into node G
<b>(d)</b>	<p><b>M1:</b> consistent flow pattern (<math>\geq 12</math>) throughout the network - so the flow into each node must equal the flow out of each node (and this flow must be greater than or equal to 12 but not necessarily the maximum flow of 15) - one number only on each arc</p> <p><b>A1:</b> CAO</p>
<b>(e)</b>	<p><b>B1:</b> CAO (for max. flow)</p> <p><b>B1:</b> Consideration of both the min. flow from the source and the flow through node C</p> <p><b>B1:</b> Completely correct argument that the max. flow = min. flow</p>
<b>(f)</b>	<p><b>B1:</b> Correct argument regarding increasing the upper capacity of arc BF and hence the flow in that arc</p> <p><b>B1:</b> Correct reasoning regarding increasing the flow in arcs FH and HT</p> <p><b>B1:</b> Correct deduction that the flow in GT decreases to 5 and conclude that all other arcs are unchanged</p>

Question	Scheme					Marks	AOs																																																																																																																													
7	<table><tr><th>Stage</th><th>State</th><th>Action</th><th>Dest</th><th>Value</th></tr><tr><td>May</td><td>2</td><td>2</td><td>0</td><td><math>700 + 1500 = 2200^*</math></td></tr><tr><td>(4)</td><td>1</td><td>3</td><td>0</td><td><math>350 + 1500 = 1850^*</math></td></tr><tr><td></td><td>0</td><td>4</td><td>0</td><td><math>1500 + 800 = 2300^*</math></td></tr><tr><td>April</td><td>2</td><td>1</td><td>0</td><td><math>700 + 1500 + 2300 = 4500</math></td></tr><tr><td>(3)</td><td></td><td>2</td><td>1</td><td><math>700 + 1500 + 1850 = 4050^*</math></td></tr><tr><td></td><td></td><td>3</td><td>2</td><td><math>700 + 1500 + 2200 = 4400</math></td></tr><tr><td></td><td>1</td><td>2</td><td>0</td><td><math>350 + 1500 + 2300 = 4150</math></td></tr><tr><td></td><td></td><td>3</td><td>1</td><td><math>350 + 1500 + 1850 = 3700^*</math></td></tr><tr><td></td><td></td><td>4</td><td>2</td><td><math>350 + 1500 + 800 + 2200 = 4850</math></td></tr><tr><td></td><td>0</td><td>3</td><td>0</td><td><math>1500 + 2300 = 3800^*</math></td></tr><tr><td></td><td></td><td>4</td><td>1</td><td><math>1500 + 800 + 1850 = 4150</math></td></tr><tr><td></td><td></td><td>5</td><td>2</td><td><math>1500 + 800 + 2200 = 4500</math></td></tr><tr><td>March</td><td>2</td><td>4</td><td>0</td><td><math>700 + 1500 + 800 + 3800 = 6800</math></td></tr><tr><td>(6)</td><td></td><td>5</td><td>1</td><td><math>700 + 1500 + 800 + 3700 = 6700^*</math></td></tr><tr><td></td><td>1</td><td>5</td><td>0</td><td><math>350 + 1500 + 800 + 3800 = 6450^*</math></td></tr><tr><td>Feb</td><td>2</td><td>1</td><td>1</td><td><math>700 + 1500 + 6450 = 8650^*</math></td></tr><tr><td>(2)</td><td></td><td>2</td><td>2</td><td><math>700 + 1500 + 6700 = 8900</math></td></tr><tr><td></td><td>1</td><td>2</td><td>1</td><td><math>350 + 1500 + 6450 = 8300^*</math></td></tr><tr><td></td><td></td><td>3</td><td>2</td><td><math>350 + 1500 + 6700 = 8550</math></td></tr><tr><td></td><td>0</td><td>3</td><td>1</td><td><math>1500 + 6450 = 7950^*</math></td></tr><tr><td></td><td></td><td>4</td><td>2</td><td><math>1500 + 800 + 6700 = 9000</math></td></tr><tr><td>Jan</td><td>0</td><td>3</td><td>0</td><td><math>1500 + 7950 = 9450^*</math></td></tr><tr><td>(3)</td><td></td><td>4</td><td>1</td><td><math>1500 + 800 + 8300 = 10600</math></td></tr><tr><td></td><td></td><td>5</td><td>2</td><td><math>1500 + 800 + 8650 = 10950</math></td></tr></table>					Stage	State	Action	Dest	Value	May	2	2	0	$700 + 1500 = 2200^*$	(4)	1	3	0	$350 + 1500 = 1850^*$		0	4	0	$1500 + 800 = 2300^*$	April	2	1	0	$700 + 1500 + 2300 = 4500$	(3)		2	1	$700 + 1500 + 1850 = 4050^*$			3	2	$700 + 1500 + 2200 = 4400$		1	2	0	$350 + 1500 + 2300 = 4150$			3	1	$350 + 1500 + 1850 = 3700^*$			4	2	$350 + 1500 + 800 + 2200 = 4850$		0	3	0	$1500 + 2300 = 3800^*$			4	1	$1500 + 800 + 1850 = 4150$			5	2	$1500 + 800 + 2200 = 4500$	March	2	4	0	$700 + 1500 + 800 + 3800 = 6800$	(6)		5	1	$700 + 1500 + 800 + 3700 = 6700^*$		1	5	0	$350 + 1500 + 800 + 3800 = 6450^*$	Feb	2	1	1	$700 + 1500 + 6450 = 8650^*$	(2)		2	2	$700 + 1500 + 6700 = 8900$		1	2	1	$350 + 1500 + 6450 = 8300^*$			3	2	$350 + 1500 + 6700 = 8550$		0	3	1	$1500 + 6450 = 7950^*$			4	2	$1500 + 800 + 6700 = 9000$	Jan	0	3	0	$1500 + 7950 = 9450^*$	(3)		4	1	$1500 + 800 + 8300 = 10600$			5	2	$1500 + 800 + 8650 = 10950$	M1 A1	3.1b 1.1b
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All M marks – must bring optimal result from previous stage into calculations so for the second stage (April) if none of their 2200, 1850 or 2300 (the optimal results from May) are used then M0. Ignore extra rows. Condone and credit rows that have been crossed out if they can still be read. Must have right ‘ingredients’ (storage costs, additional space costs, overhead cost) at least once per stage. Must have values in two of the three columns (State, Action, Dest). If no working seen then the number stated in the Value column must be correct to imply the correct method has been used																																																																																																																																				

- 1M1:** First stage (May) completed. At least 3 rows, ‘something’ in each cell (but see M mark guidance above) including the correct structure (e.g. no value greater than 5 in the action column) in each of the first four columns
- 1A1:** CAO for first stage.
- 2M1:** Second stage (April) completed. At least 9 rows, something in each cell (see M mark guidance above) including the correct structure for the fifth (Value) column (e.g. bringing forward values from the previous stage)
- 2A1:** CAO for second stage. No extra rows
- 3M1:** Third stage (March) completed. At least 3 rows, something in each cell (see M mark guidance above)
- 3A1ft:** CAO on the ft for third stage. No extra rows
- 4M1:** Fourth stage (February) completed. At least 6 rows, something in each cell (see M mark guidance above)
- 4A1ft:** CAO on the ft for fourth stage. No extra rows
- 5M1:** Fifth stage (January) completed. At least 3 rows, something in each cell (see M mark guidance above)
- 5A1:** CAO for the fifth stage. No extra rows
- 1B1:** CAO – **but must have scored all previous M marks**
- 2B1:** CAO – condone lack of units - **but must have scored all previous M marks**