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MATHEMATICS

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Introduction

Our examiners' reports are produced to offer constructive feedback on candidates' performance in the examinations. They provide useful guidance for future candidates. The reports will include a general commentary on candidates' performance, identify technical aspects examined in the questions and highlight good performance and where performance could be improved. The reports will also explain aspects that caused difficulty and why the difficulties arose, whether through a lack of knowledge, poor examination technique, or any other identifiable and explainable reason.

Where overall performance on a question/question part was considered good, with no particular areas to highlight, these questions have not been included in the report. A full copy of the question paper can be downloaded from OCR.

Paper 4737/01 series overview

4737 Decision Mathematics 2 is one of the optional applied examination units for 7890 A2 Mathematics and 7892 A2 Further Mathematics.

This unit tests modelling real-life situations involving matchings, allocations, network flows, game theory and critical path analysis, commenting on and interpreting the output of the model.

Candidate performance overview

Candidates coped well on this paper, demonstrating a good understanding of the material and being well prepared for the types of questions that were asked.

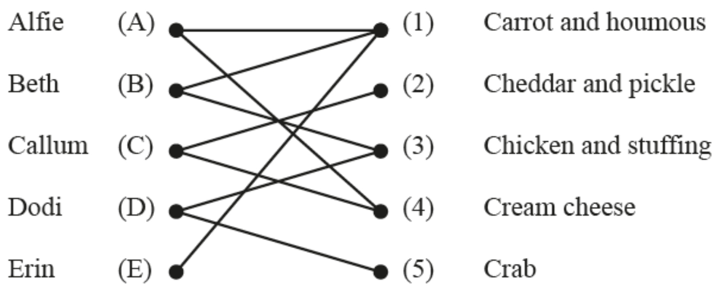
Most candidates took care to present their answers neatly and some even apologised if they had needed to replace a messy answer.

A few candidates had messy handwriting that was difficult to read and some had overwritten answers (particularly on diagrams or grids, even when a spare grid was provided) leaving a result that was impossible to read.

There was no evidence that candidates were short of time.

Question 1 (i)

1 Five students have bought a five pack of sandwiches for their lunch. The bipartite graph below shows which student likes which sandwich.



Initially Alfie chooses carrot and houmous, Callum chooses cream cheese and Dodi chooses chicken and stuffing.

(i) Draw this initial incomplete matching. **[1]**

Question 1 (ii)

(ii) Construct a shortest alternating path starting from Erin (E).
Draw the matching that this gives. **[2]**

Question 1 (iii)

(iii) Construct a shortest alternating path starting from Crab (5) to improve the incomplete matching from part **(ii)**.
List the complete matching that this gives. **[2]**

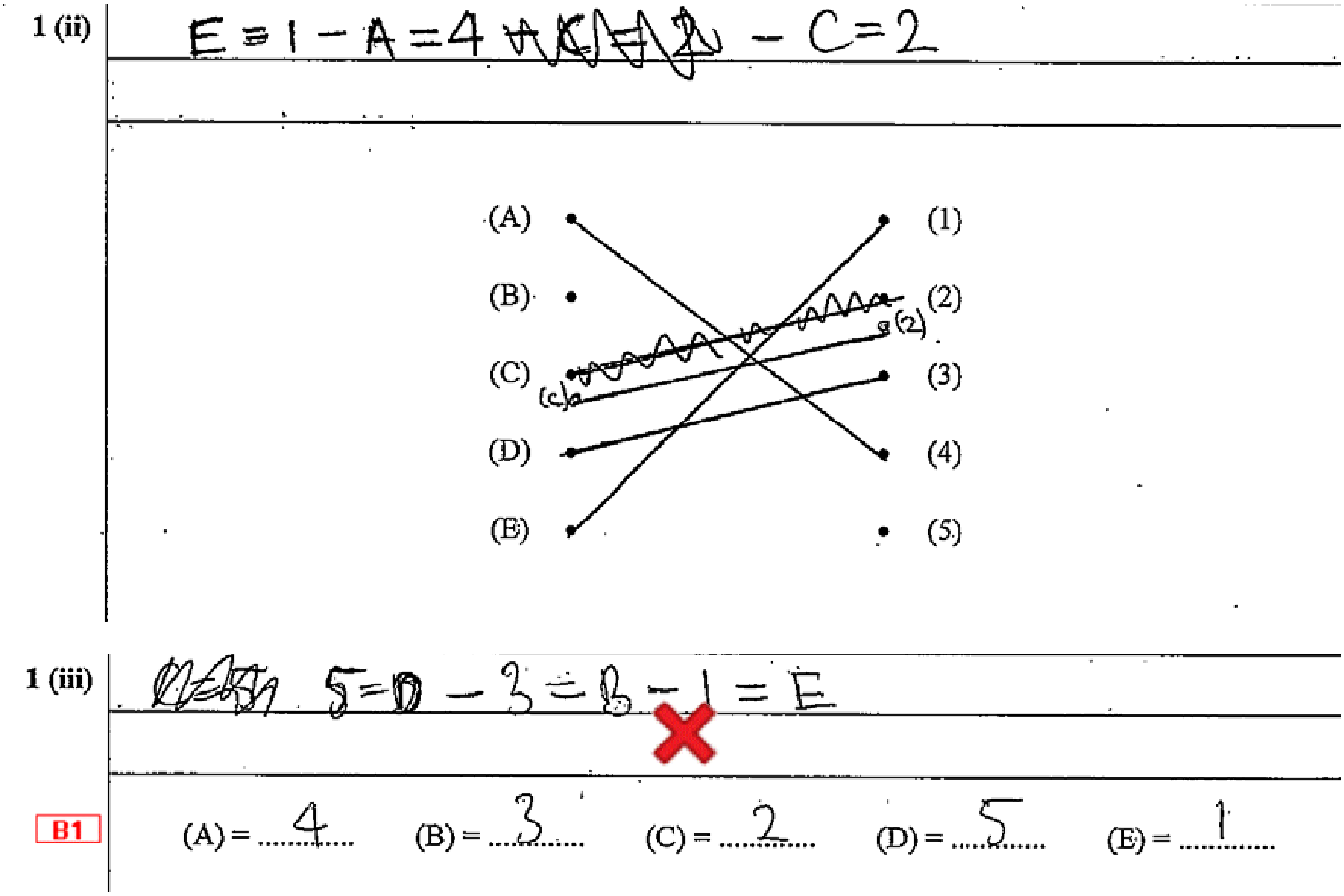
Question 1 (iv)

Suppose that, in addition to the preferences shown in the bipartite graph above, Erin had also liked crab sandwiches.

(iv) Draw a bipartite graph to show a complete matching in which Erin chooses the crab sandwich. **[1]**

Question 1 was successfully completed by most candidates with nearly all of them recognising that they were asked for shortest alternating paths. Only a very small minority could not find a suitable matching in part (iv).

Exemplar 1

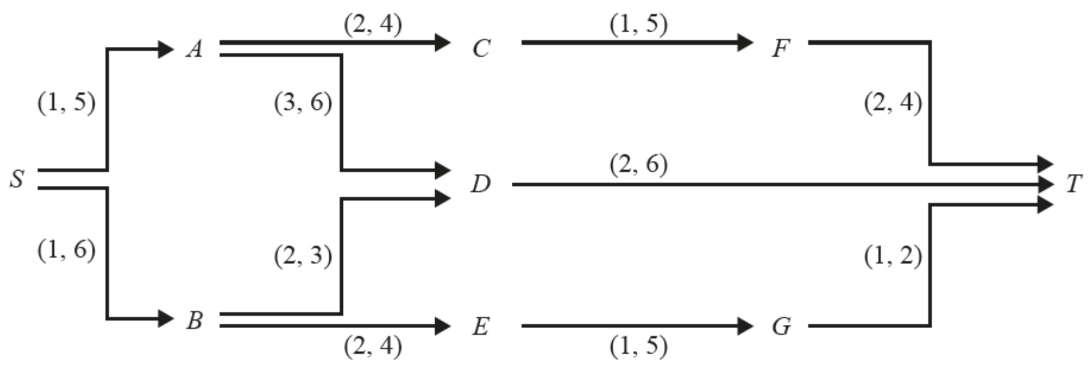


In part (ii) this candidate had deleted arc C = 2 from the solution by crossing it out (this is much preferable to erasing the arc, which sometimes leaves it still showing through on the scan), although in fact the candidate then replaced the arc anyway.

In part (iii) the candidate extends the shortest alternating path to pick up 1 = E (which was already in the improvement from part (ii)) so they do not get the mark for the path, but they do get the mark for the matching.

Question 2 (i)

2 The flow of oil through an engine is modelled in the network below. The arcs represent components of the engine. The weights on the arcs show the minimum and maximum rate of flow, in cl per second, around each component. All flows are directed as shown. From T the oil is passed back to S and topped up, if necessary, so that the oil can pass through the engine continuously.



(i) Explain why the flow in arc SA is at its maximum value. **[1]**

Question 2 (ii)

(ii) Explain why the flow in arc FT is at its minimum value. **[1]**

Most candidates gave good explanations involving the minimum flow out of *A*, through *AC* and *AD*, and hence the maximum flow into *A*, then observing that the flow in *FT* can only come from *ACFT* to deduce *FT*.

Question 2 (iii) (a)

(iii) (a) Show a flow of 9 cl per second from S to T. **[1]**

Using the results from parts (i) and (ii) meant that a suitable flow could be found.

Question 2 (iii) (b)

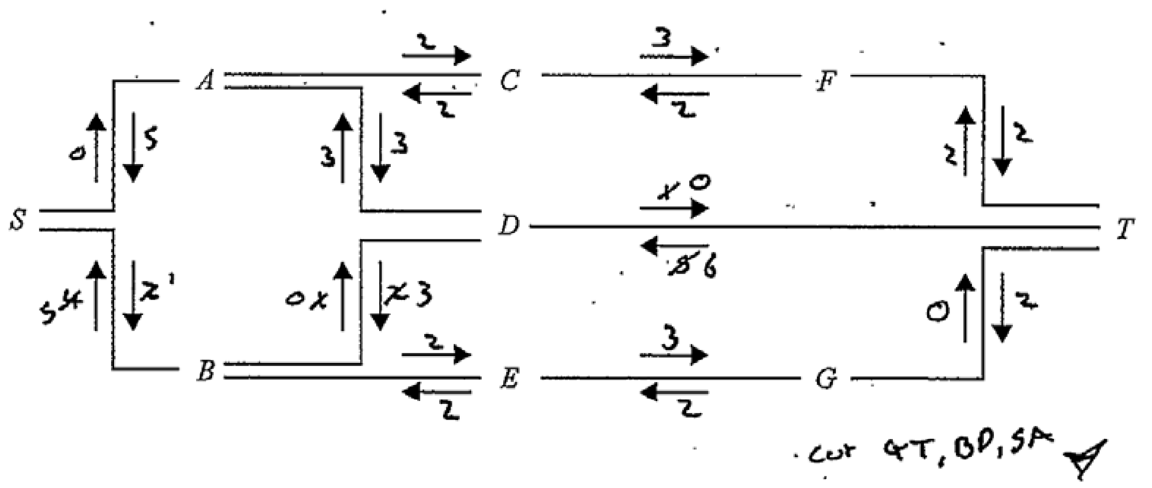
(b) Label the arrows in the diagram in the Printed Answer Book to show the excess capacities and potential backflows. **[2]**

A few candidates used the arrows the wrong way round; the arrows in the direction of the original flow should show the excess capacities (how much more could flow through an arc) and the arrows in the direction that is opposite to the original flow should show the potential backflows (how much less could flow through an arc).

Some candidates were not able to cope with the potential backflows and lower capacities. The question had been designed to enable such candidates to still be able to answer the subsequent parts.

Exemplar 2

(b)(c)(d)



Augmented route: S – B – D – T

Cut: {S, B, E, G}, {A, C, D, F, T} = 10

This candidate had the correct flow in part (iii)(a). This means that there is 5 flowing along *SA*, which has an upper capacity of 5 and a lower capacity of 1, so no more can flow (excess = 0), but up to 4 less could flow (potential backflow). The candidate has shown the excess as 0, but has shown the potential backflow as 5 (which is the flow). The potential backflow is the same as the flow when the lower capacities are 0, but when the lower capacities are not 0 the flow cannot all be removed.

The candidate has all the potential backflows marked as flows. Some candidates had a mixture of correct potential backflows and flows.

Because the excess capacities are correct, the flow augmenting route can still be found, and the values on the arrows adjusted by reducing 1 from route *S* to *T* and adding 1 to route from *T* to *S*. When augmenting with the labelling procedure there is no need to refer back to the original direction of flow, so sometimes a potential backflow is increased and the excess capacity decreased and sometimes the potential backflow is decreased and the excess capacity increased (a portion of flow is rerouted).

When it is no longer possible to augment further the flow from *S* to *T*, no matter how obscure the route taken, the maximum flow has been achieved and any arcs that have no further potential flow from the source to the sink either have excess capacity 0 and are saturated (full to capacity) or are opposing the flow and are as empty as possible. There will be a cut that separates the source from the sink that uses only arcs with a 0 on the arrow across the cut from the source side to the sink side.

Sometimes the cut can be drawn on the diagram, but this is not always possible, particularly with a non-planar graph, so listing the vertices in the source set and the sink set is a safer way to indicate the cut. The cut arcs are those with one end in the source set and the other end in the sink set. In this question candidates only needed to find a suitable cut (eg {*S*, *B*, *E*, *G*}, {*A*, *C*, *D*, *F*, *T*} or {*S*, *B*, *D*, *E*, *G*}, {*A*, *C*, *F*, *T*}), but some also explained how this together with the flow found in part (iii)(a) shows that this is a maximum flow.

Question 2 (iii) (c)

(c) Use the labelling procedure to augment the flow to 10 cl per second. Write down the route that has been augmented. **[2]**

Question 2 (iii) (d)

(d) Find a cut that shows that 10 cl per second is the maximum flow. **[1]**

Question 3 (i)

3 The publicity team at a college want to advertise four events. The events are for different age groups, so nobody will attend more than one event and each event will be advertised in a different way.

For each method of advertising, the number of people who are expected to turn up is shown in the table below. The team want to know which advertising method to use for which event to maximise the total number of people who attend the four events.

	Advertising method			
	newspaper	posters	emails	on buses
Event 1	1000	600	200	200
Event 2	800	500	300	200
Event 3	500	400	300	100
Event 4	1000	300	400	200

(i) Convert this into a suitable form so that the problem can be solved using the Hungarian algorithm with single digit entries in each cell of the initial matrix. **[2]**

The answer space gave a grid for working and a grid for final answer, some candidates only needed one grid and that was fine.

Most candidates realised that they needed to convert the problem into a minimisation problem, for example by subtracting each value from 1000; those who missed this usually spotted it in their working for part (ii).

Quite a few candidates ignored the instruction to use single digit entries. This was achieved by scaling, for example by 100 and was intended to help candidates to not need to write a lot of 00's. Those who did not use the multiplicative scaling should have gone on to achieve a solution that was exactly 100 times the intended solution throughout. This was accepted in part (ii).

Question 3 (ii)

(ii) Use the Hungarian algorithm, reducing rows first, to find an optimal allocation. Give a brief description of what you have done to form each table. **[5]**

Most candidates gave very good answers to this part, explaining the construction of the tables and carrying out the arithmetic accurately. Some candidates reduced rows only and forgot to reduce columns as well before starting to augment. A few used more lines than were needed for the crossing out and some augmented a table when they had already said that it could be crossed out using (a minimum of) 4 lines.

Question 3 (iii)

(iii) Which method should be used to advertise each event and what is the total number of people who are expected to turn up to the four events? **[2]**

Advertising on buses is too expensive for the returns it gives, so the team decide to use a leaflet drop instead. The number of people who are expected to turn up for each event if it is advertised in this way are:

Event 1 = 120 Event 2 = 120 Event 3 = 20 Event 4 = 120

(iv) Explain why the events being advertised using newspaper adverts, posters and emails are the same as in part **(iii)**. You do not need to carry out the full Hungarian algorithm again. **[1]**

Question 3 (iv)

This part was about linear transformations and the effect that they have on the solution. For each event, the expected number of people when advertising using a leaflet drop is exactly the same as when advertising on buses. If columns are reduced first, both would give the same reduced cost matrix and so both have the same solution.

Question 4 (i) (a)

4 Leo and Maya play a card game. The game involves each player being dealt three cards from a set of eight cards (labelled A to H). Each player chooses one of their cards. The players then simultaneously show their choices and deduce how many points they have won or lost using the table below.

The table shows the number of points won by the player **on rows** for each pair of cards. A negative entry means that the player loses that number of points. The game is zero-sum.

	A	B	C	D	E	F	G	H
A		−1	−1	−2	−2	−3	−3	6
B	1		−1	−1	−2	−2	4	5
C	1	1		0	0	−3	0	5
D	2	1	0		−1	−2	−3	−4
E	2	2	0	1		−1	−2	−4
F	3	2	3	2	1		−6	−6
G	3	−4	0	3	2	6		−6
H	−6	−5	−5	4	4	6	6	

(i) In the first game Leo is dealt cards A, D and E. Maya is dealt cards B, F and H. Each player knows which cards the other has.

(a) Write out the pay-off matrix for Leo, with Leo on rows, when they play with these six cards. Hence find the play-safe choice(s) for each player. **[4]**

A few candidates gave the entire table, or put Leo on columns and Maya on rows, but most did as they had been asked and showed the appropriate pay-off matrix. The play-safe strategies could then be found using the row maximin and column minimax (the negative of the maximin of the pay-offs for Maya).

The play-safe for Leo is A and the play-safe for Maya is F.

Question 4 (i) (b)

(b) If each player plays safe how many points would Maya win? **[1]**

When Leo plays A and Maya plays F, Leo wins -3 points. The game is zero-sum so Maya wins +3 points. Some candidates gave the entry -3 for Leo and forgot to interpret the result in terms of Maya's points.

Question 4 (i) (c)

(c) If Leo knows that Maya will play safe, which card should he choose to maximise the points that he wins? **[1]**

If Leo knows that Maya will play column F, he could win -3 (by playing A), -4 (by playing D) or -1 (by playing E). The best of these, for Leo, is to play E.

Some candidates forgot that Leo is only choosing between cards A, D and E and suggested that Leo should play G or H.

Question 4 (ii) (a)

(ii) In the second game Leo is again dealt cards A, D and E. This time Leo does not know which cards Maya has, although she knows which cards he has.

(a) Explain why this makes no difference to Leo's play-safe choice. **[1]**

Many candidates gave answers that essentially just described what a play-safe strategy is. Some candidates assumed that Maya was still playing with B, F and G still and some assumed that she could have any of the 8 cards instead of just the 5 cards that were not already taken by Leo.

Using the five columns B, C, F, G, H and the rows A, D, E give row minima of -3, -4, -4 so A is still the strategy where the row minimum is greatest.

Question 4 (ii) (b)

(b) If Maya knows that Leo will play safe, which are the worst three cards for Maya to have if she wants to maximise the points that she wins? **[1]**

Again, several candidates made assumptions about which cards Leo and Maya had. The stem to part (ii) had said that Maya knows which cards Leo has, so Maya knows that Leo will play-safe and choose card A. When Leo plays card A, the worst cards for Maya (excluding A, D and E) are those in row A where Leo's points score is highest ie H, B and C.

Question 4 (iii)

(iii) In the third game Maya is dealt cards B, F and H. This time neither player knows which cards the other has. Maya wants to maximise the points that she wins.

Give a reason, based on the values in the table, why Maya might choose each of her cards. **[3]**

This was a style of question that was slightly different to what had been asked before. The intention was to find a reason why Maya would choose each of her cards in preference to each of the others.

Candidates often overlooked the fact that Leo now has three of the five cards A, C, D, E and G and not his original three cards or three cards chosen from the full set of 8 cards.

Remembering that Maya's wins are the negatives of the points in the table, the minimum points that Maya can win in each of her columns are B = -2 (when Leo plays E), F = -6 (when Leo plays G) and H = -6 (when Leo plays A). If Maya plays B she will lose at most 2 points, instead of potentially losing 6 points with F or H. Her play-safe strategy is B.

Column F has just one row where Maya loses points (rows G) and four where she gains points (A, C, D and E), so she wins with four out of the five possibilities. This is better than B (2 out of 5) and H (3 out of 5).

Column H gives her the greatest possible gain (6, if Leo plays G), instead of 4 from column B (when Leo plays G) or 3 from column F (when Leo plays A or B).

Question 5 (i)

5 The table below shows an incomplete dynamic programming tabulation to solve a maximin problem.

Stage	State	Action	Working	Suboptimal maximin
3	0	0	4	4
	1	0	3	3
2	0	0	min (2,) =	
		1	min (4,) =	
	1	0	min (3,) =	
		1	min (2,) =	
	2	0	min (5,) =	
		1	min (2,) =	
1	0	0	min (2,) =	
		1	min (5,) =	
	1	1	min (2,) =	
		2	min (2,) =	
0	0	0	min (4,) =	
		1	min (3,) =	

(i) Complete the working and suboptimal maximin columns on the copy of the table in your Printed Answer Book. Write down, using (stage; state) variables, the corresponding maximin route from stage 0 to stage 4. **[6]**

There were many correct answers here. Candidates are usually able to carry out dynamic programming, even for maximin and for minimax, when they are given the structure of the table. A few made numerical errors, or did not complete the suboptimal maximin values and some omitted (4; 0) from the route.

Question 5 (ii)

(ii) Record the weight of each of the arcs in the maximin route. Use these weights to explain what a maximin route is. **[3]**

The maximin route was (0; 0) – (1; 0) – (2; 1) – (3; 0) – (4; 0). The weights of these arcs could be found from the printed values in the table: (0; 0) to (1; 0) has weight 3, (1; 0) to (2; 1) has weight 5, (2; 1) to (3; 0) has weight 3, and (3; 0) to (4; 0) has weight 4. This required candidates to understand how the table is constructed, for example for arc (1; 0) to (2; 1) use the row for stage 1, state 0 and action 2.

Quite a few candidates were able to do this, although some had drawn out the network on the back page of the answer booklet. Examiners followed through incorrect routes from part (i).

The minimum of the arc weights 3, 5, 3 and 4 is 3 and this is greater than (or possibly equal to) the minimum weight for all other routes. Several candidates gave long explanations involving the arcs of weight 2.

Question 5 (iii) (a)

Sally solves a different problem on the same network and produces the following table.

Stage	State	Action	Working	Suboptimal
3	0	0	4	4
	1	0	3	3
2	0	0	$2 + 4 = 6$	
		1	$4 + 3 = 7$	7
	1	0	$3 + 4 = 7$	7
		1	$2 + 3 = 5$	
	2	0	$5 + 4 = 9$	9
		1	$2 + 3 = 5$	
1	0	0	$2 + 7 = 9$	
		1	$5 + 7 = 12$	12
	1	1	$2 + 7 = 9$	
		2	$2 + 9 = 11$	11
0	0	0	$4 + 12 = 16$	16
		1	$3 + 11 = 14$	

(iii) (a) What problem has Sally solved? **[1]**

Question 5 (iii) (b)

(b) Write down the route that is given by Sally's tabulation. **[1]**

Question 5 (iii) (c)

(c) Use the arc weights to explain how Sally's route solves her problem. **[1]**

Candidates usually saw that Sally's suboptimal values were maxima and that her working values were sums, so she is solving a maximum weight path (longest path) problem. Tracing back through the table gave (0; 0) suboptimal value 16 comes from action 0, so (1; 0), then (1; 0) suboptimal value 12 comes from action 1, so (2; 1), and so on, to give the path (0; 0) – (1; 0) – (2; 1) – (3; 0) – (4; 0). This was the same path as in part (i) so the arc weights had already been found in part (ii). Using these arc weights gives a total for the route of 4+5+3+4 = 16 and no other route gives a larger total.

Some candidates said that Sally had chosen the arcs with the largest weights rather than the route with the greatest total. The arcs with the largest weight would not have formed a route – (2; 2) to (3; 0) and (1; 0) to (2; 1) each have weight 5, but these are not on the same route.

Question 6 (i)

6 **(i)** State three properties that a game must possess to be a two-person zero-sum game. **[3]**

The first part of this question was about what kinds of 'games' are studied in game theory and which are not. Most candidates were able to explain zero-sum and some realised that they could also describe two-person, the 'hidden' property was 'simultaneous play'. Some candidates gave three different explanations of zero-sum, or worried about players collaborating, finding play-safe strategies or made claims about the number of strategies each player was choosing between.

Question 6 (ii)

Usha, Val and Wesley are in a quiz team. They have been practising for the championship final.

The final will consist of 100 questions from the four topics shown in the table below.

The table shows the number of points, out of 10, that each person can expect to score on a question from each topic that could come up.

Topic

	Famous faces	Films	Food	Football
Usha	5	3	7	3
Val	2	4	1	4
Wesley	3	5	2	6

Only two of the team can play in the final. Either of them can be chosen to answer each question, but the team have to choose who will answer each question before they know the topic for the question.

Usha is the team captain, so she will play in the final. She has to reject either Val or Wesley.

(ii) Who should not play in the final? Explain why that person should be rejected. **[2]**

Most candidates said that Val should be rejected because of dominance. Many of the candidates also described the dominance correctly – for each topic, Val's score is lower than Wesley's – and several showed the relevant inequalities as well ($2 < 3$, $4 < 5$, $1 < 2$, $4 < 6$).

Question 6 (iii)

Usha decides to use random numbers to choose who will answer each question.
Let p be the probability that Usha answers a question, where p is the same for each question.

(iii) Write down an expression of the form $a + bp$, where a and b are constants, for the expected number of points won if each topic comes up. **[3]**

A few numerical slips were seen, and some candidates used the rows for Usha and Val although they had rejected Val in part (ii). If a candidate had rejected Wesley in part (ii) this was followed through. Some candidates left their answers in terms of p and q, where $q = 1 - p$ and a few used all three rows with probabilities p, q and r (or sometimes p, $1 - p$ and again $1 - p$, which do not sum to 1)

Question 6 (iv)

(iv) Use a graphical method to calculate the value of p that Usha should use to maximise the minimum expected number of points won. **[4]**

The horizontal axis should show p from 0 to 1 and should fill at least half the width of the grid (for example 1 small square = 0.1 horizontally). The vertical axis (expected pay-off or E) should cover the spread of values in the V and W columns of the table (which may be positive or negative) and usually also 0, with a sensible scale (in this case from 0 to 7, using one small square = 1).

Those candidates who had rejected Wesley should have two of their equations the same, so they only have three lines, but those who have rejected Val should have four lines. The lower boundary defines the minimum points score for each value of p, and the highest point on this lower boundary gives the maximin. This is where $5 - 2p = 3 + 2p$, which gives the optimal value of p as 0.5

Some candidates chose the wrong intersection, with $p = 1/3$ being a common wrong answer.

Question 6 (v)

Suppose instead that all three team members can play in the final. Let p be the probability that Usha answers a question, with q and r being the corresponding probabilities for Val and Wesley, respectively.

(v) Set up an initial Simplex tableau for the problem of choosing the optimal values for p, q and r to maximise the minimum expected number of points won. You are not required to solve your LP. **[4]**

This part tested the second part of the specification item 'determine an optimal mixed strategy for a game with no stable solution (i) by using a graphical method for $2 \times n$ or $n \times 2$ games, where $n = 1$, 2 or 3, (ii) by converting higher order games to linear programming problems that could then be solved using the Simplex method'. Candidates were not required to apply the Simplex algorithm, as some of them seemed to have assumed.

To formulate the problem the coefficients of p, q and r need to be non-negative and usually this would involve adding a constant throughout, but in this case the coefficients were already non-negative. The problem is then converted to the form: maximise M = m, where m $\leq$ each of the expressions for expected pay-off, and total probability ≤ 1. The total probability will equal 1 in the optimal solution because the coefficients are all non-negative, but this constraint is needed as an inequality to enable the Simplex algorithm to (at some point) pivot on this row and hence increase the value of M.

There have been questions asking about the formulation of a Simplex tableau or the interpretation of a tableau before. This was essentially the same thing, but asking candidates to set up the initial tableau.

The constraints needed to be rewritten in the standard form and have slack variables added to form equations; these then needed to be converted into an initial tableau.

Exemplar 3

6 (v)

maximise $M = m$ $\quad M - m = 0.$

Subject to: $m \leqslant 5p + 2q + 3r$

$m \leqslant 3p + 4q + 5r$

$m \leqslant 7p + q + 2r$

$m \leqslant 3p + 4q + 6r$

$p + q + r \leqslant 1$

$p, q, r, m \geqslant 0$

$\Rightarrow$ $m - 5p - 2q - 3r + s = 0.$

$m - 3p - 4q - 5r + t = 0$

$m - 7p - q - 2r + u = 0.$

$m - 3p - 4q - 6r + v = 0$

Initial Simplex tableau (you may not need all these rows and columns)

M	m	p	q	r	s	t	u	v	value	θ			
1	-1	0	0	0	0	0	0	0	0				
0	1	-5	-2	-3	1	0	0	0	0				
0	1	-3	-4	-5	0	1	0	0	0				
0	1	-7	-1	-2	0	0	1	0	0				
0	1	-3	-4	-6	0	0	0	1	0				
0	0	1	1	1	0	0	0	0	1				

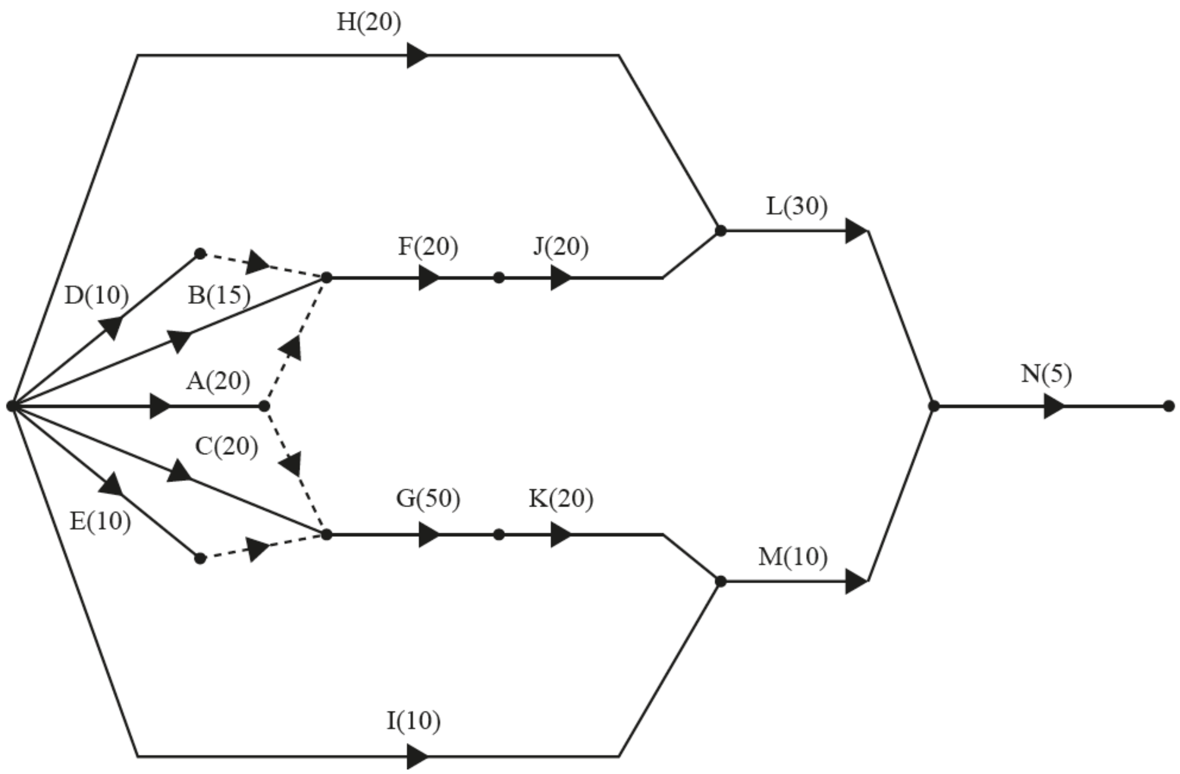
This candidate has formulated the problem and has added slack variables to the four constraints involving m, but has overlooked adding slack to the constraint $p + q + r \leq 1$. This has then all been transferred to an initial Simplex tableau. There should be a fifth slack variable, w, corresponding to $p + q + r + w = 1$, but this constraint has already been credited in the algebraic formulation so the candidate gets full marks even with a slack variable missing.

Question 7 (i)

7 The table lists the activities involved in making cupcakes and carrot cake slices for a bake sale, their durations (in minutes) and their immediate predecessors.

Activity		Duration (mins)	Immediate predecessors
Heat oven	A	20	
Mix cupcakes	B	15	
Mix carrot cakes	C	20	
Line cupcake tins with paper cases	D	10	
Prepare cake tins for carrot cakes	E	10	
Bake cupcakes	F	20	A, B, D
Bake carrot cakes	G	50	A, C, E
Make topping for cupcakes	H	20	
Make topping for carrot cakes	I	10	
Let cupcakes cool	J	20	F
Let carrot cakes cool and slice	K	20	G
Decorate cupcakes	L	30	H, J
Decorate carrot cake slices	M	10	I, K
Pack cupcakes and carrot cake slices into boxes	N	5	L, M

This information is represented in the activity network below.



(i) Carry out a forward pass and a backward pass through the activity network. Show the early event times and the late event times at each vertex on the copy of the activity network in the Printed Answer Book. **[3]**

The forward and backward passes needed some care because of merges and bursts that involved dummy activities. Most candidates were able to deal with these and calculate the early and late event times accurately.

Question 7 (ii)

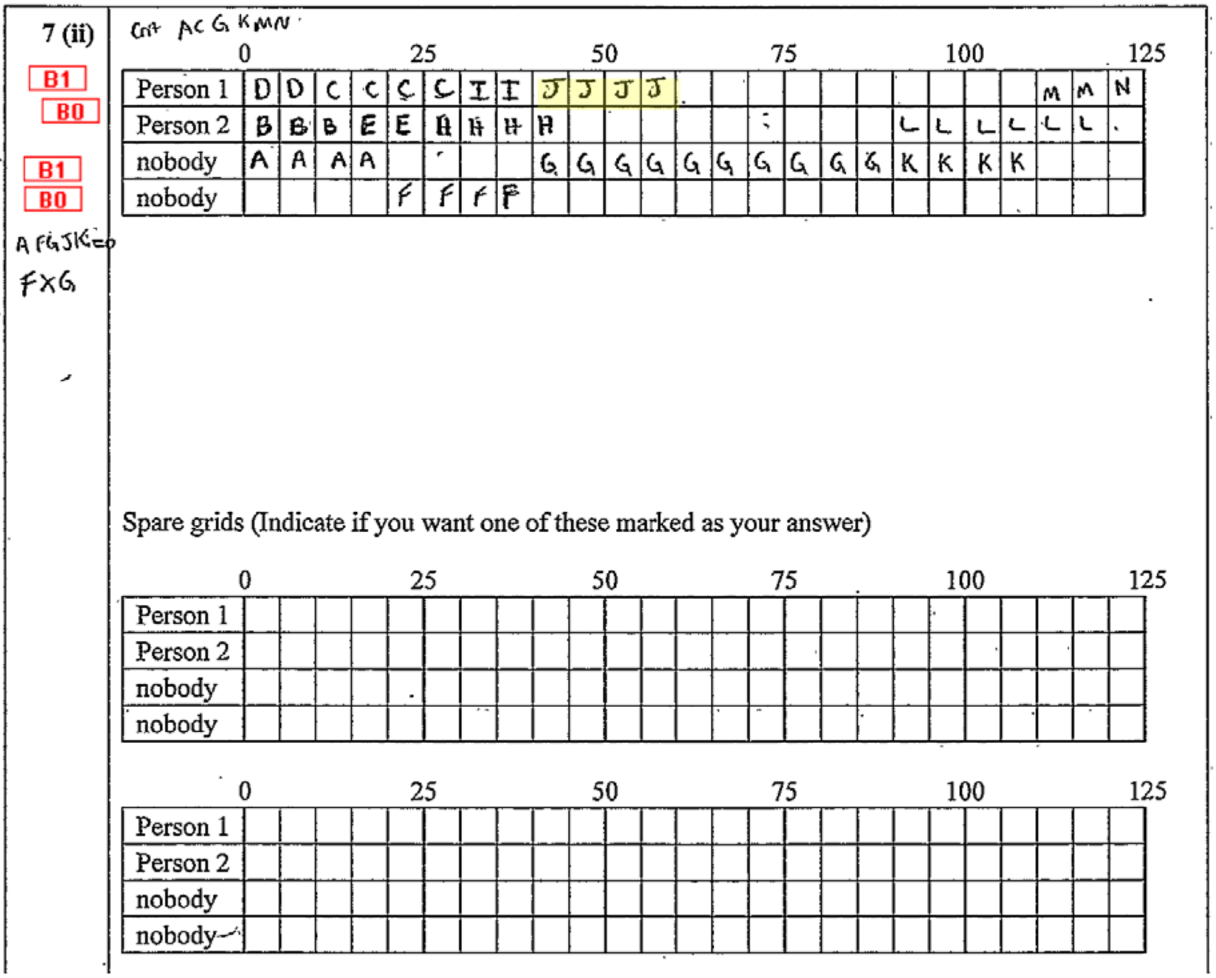
Assume that activities A, F, G, J and K require no people. All other activities require one person.
The cupcakes cannot be baked in the same oven as the carrot cakes and there is only one oven available, so activities F and G cannot happen at the same time.

(ii) Construct a schedule to show how two people can complete the activities in 125 minutes. **[4]**

Candidates were given spare grids and most who had used a spare grid politely informed examiners which grid they wanted marked. Despite having spare grids, some candidates wrote over errors and ended up with grids that could not be marked because they were impossible to read.

There was some spare time, so the potential clashes when three people or two ovens would have been needed could be avoided. Some care was needed to construct a suitable schedule. Some candidates had activities that needed people (such as decorating the cakes) being done by nobody, or activities that needed nobody being done by one of the people.

Exemplar 4



7 (ii)

B1 B0 B1 B0

Crit ACGKMN

0 25 50 75 100 125

Person 1	D	D	C	C	C	C	I	I	J	J	J	J											M	M	N
Person 2	B	B	B	E	E	H	H	H	H										L	L	L	L	L	L	
nobody	A	A	A	A					G	G	G	G	G	G	G	G	G	G	K	K	K	K			
nobody					F	F	F	F																	

A F G J K = 0

F × G

Spare grids (Indicate if you want one of these marked as your answer)

0 25 50 75 100 125

Person 1																									
Person 2																									
nobody																									
nobody																									

0 25 50 75 100 125

Person 1																									
Person 2																									
nobody																									
nobody																									

This candidate has given a correct schedule, except for having Person 1 doing activity J (let cupcakes cool) instead of this activity being done by nobody.

Question 7 (iii)

Now suppose that there is only one person available. Two possible sets of activity start times are listed below.

Version (1): bake cupcakes first

Activity	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Start time	0	0	25	15	45	25	55	55	75	45	105	85	125	135

Project completion time 140 minutes

Version (2): bake carrot cakes first

Activity	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Start time	0	30	0	45	20	80	30	55	75	100	80	120	100	150

Project completion time 155 minutes

(iii) Find the project completion time for each of these versions if two ovens were available instead of one. **[2]**

There was an element of having to try out some possibilities here, which is why it was positioned as the last part of the final question.

The schedule given in version 1 (bake cupcakes first) has a break between the cupcakes coming out of the oven (at time 45) and the carrot cakes going in (at time 55) so there will be no change if two ovens are available. The time is still 140 minutes.

The schedule given in version 2 (bake carrot cakes first) can be shortened if two ovens are available. Some candidates claimed that the time could be reduced to 130 minutes, but this did not take into account the delay in waiting for the cupcakes to cool before they can be decorated. The time could be reduced by 15 minutes and was also 140 minutes.

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