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Examiners' report

FURTHER MATHEMATICS B (MEI)

H635

For first teaching in 2017

Y413/01 Summer 2022 series

Contents

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. A selection of candidate answers is also provided. The reports will also explain aspects which 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 and the mark scheme can be downloaded from OCR.

Advance Information for Summer 2022 assessments

To support student revision, advance information was published about the focus of exams for Summer 2022 assessments. Advance information was available for most GCSE, AS and A Level subjects, Core Maths, FSMQ, and Cambridge Nationals Information Technologies. You can find more information on our website.

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Paper Y413/01 series overview

June 2022 was the third summer examination series for the Linear H635 AS Further Maths B (MEI) optional paper Y413 (Modelling with Algorithms). It was extremely pleasing to note that most candidates were well prepared for the examination making good attempts on all questions. Candidates seemed to have enough time to answer the questions and nearly all seemed to make good use of the Printed Answer Booklet (that is very few answers to one question appeared in the part for another or in the Additional Answer Space). Based on the responses seen by examiners this series the following general points should be considered by centres in preparation for candidates for future sittings of this paper.

- Diagrams should be completed in pencil so that candidates can rub out and replace their answer rather than trying to correct in pen on what is likely to be a diagram, which does not have enough space for multiple attempts. This was especially true in Question 4 (f) (scheduling activities) in which it was difficult at times for examiners to know if crossing out was candidates' genuinely trying to correct an error or was the candidates attempt to schedule the workers to tasks.

- This unit is primarily a methods examination and so it is vital that candidates make their method and application of any corresponding algorithm clear; spotting and writing down the solution (for example in the flow chart question) will rarely gain any credit.

- The specification (on page 8) contains a section on the meanings of several instructions that will be used in examination questions – one of the key words that could appear (as it did in this paper) is the word 'determine' – the word 'determine' in this mathematical context requires that justification should be given for any results found and not just the writing down or stating of the answer.

- Candidates are reminded to use the number of marks available as the main guide to how detailed their answer should be and not the space given in the Printed Answer Booklet. It is always hoped that the PAB should provide enough space for the candidate's response, which often includes additional space so candidates can correct any errors.

Candidates who did well on this paper generally did the following:	**Candidates who did less well on this paper generally did the following:**
• applied the corresponding algorithm correctly and showed detailed working/reasoning (and therefore did not rely on ad-hoc methods) • read questions carefully and provided the answers that were requested • made efficient use of their calculator.	• did not give sufficient detail in questions which required an explanation or the command to 'determine' their answer • used imprecise notation or language.

Question 1 (a) (i)

1 (a) (i) State the number of arcs in the complete graph with 6 nodes. **[1]**

Most candidates correctly gave the answer of 15 (by considering the calculation $\frac{6\times 5}{2}$).

Question 1 (a) (ii)

(ii) State the minimum number of arcs in a simply connected graph with 6 nodes. **[1]**

This was one of the best answered parts of the paper – nearly all candidates gave the correct of 5 (coming from the fact that the minimum number of arcs in a simply connected graph with n nodes is $n-1$).

Question 1 (b) (i)

(b) (i) Using the nodes in the Printed Answer Booklet, draw the graph described by the incidence matrix below. **[1]**

$$\begin{array}{c c} & \begin{array}{ccccc} \mathrm{A} & \mathrm{B} & \mathrm{C} & \mathrm{D} & \mathrm{E} \end{array} \\ \begin{array}{c} \mathrm{A} \\ \mathrm{B} \\ \mathrm{C} \\ \mathrm{D} \\ \mathrm{E} \end{array} & \begin{pmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 2 & 0 & 1 \\ 1 & 2 & 2 & 0 & 3 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 3 & 1 & 0 \end{pmatrix} \end{array}$$

Although most candidates answered this part correctly, a number either did not draw a loop at node C or did not have two arcs between nodes B and C.

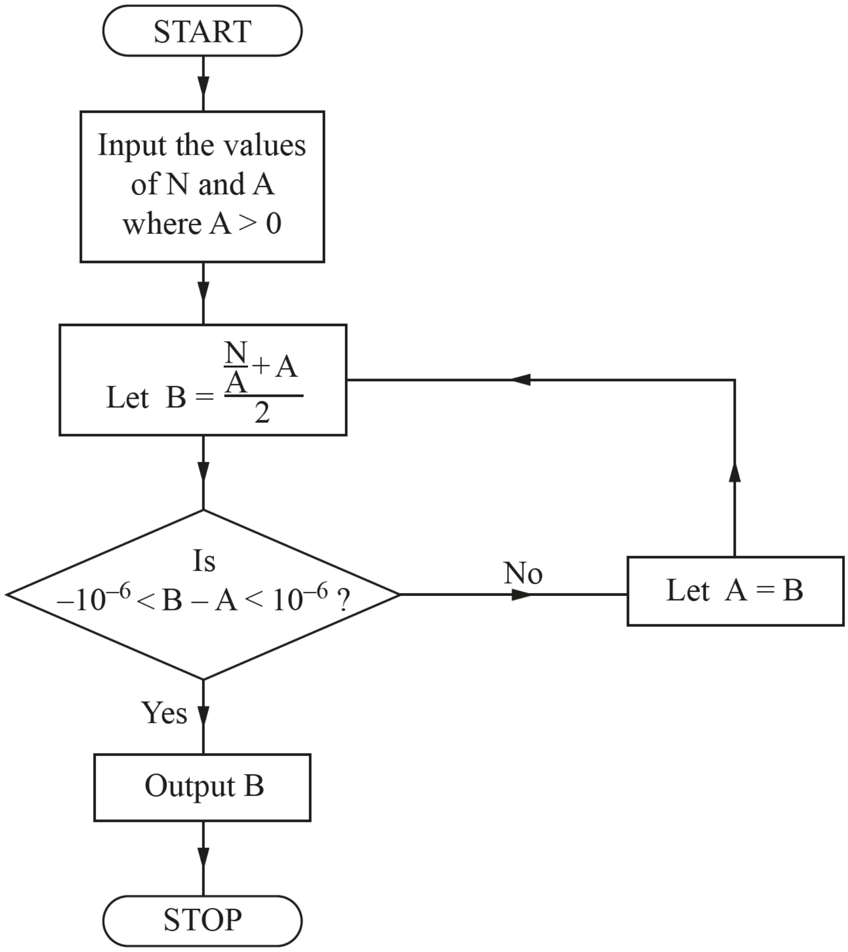
Question 1 (b) (ii)

(ii) State the order of node C. **[1]**

Most candidates either used their answer to (b) (i) or realised that the order of node C could be found from summing the values in either the C row or column from the incidence matrix.

Question 2 (a)

2 A process for finding a square root of the positive real number N is described by the flow chart below.



(a) Explain why the process described by the flow chart is an example of an algorithm. **[1]**

Although many candidates had the correct idea that the algorithm would solve the problem of finding the square root for the input N, many did not articulate that an algorithm contains a finite sequence of operations for solving a problem.

Question 2 (b)

(b) Work through the algorithm using the inputs N = 73 and A = 8. Record the values of A and B, to at least **9** decimal places where necessary, every time they change.
Give the final output correct to **7** decimal places. **[3]**

Many candidates did not do as the question requested (which was to record the values of A and B to at least 9 decimal places and to give the final output correct to 7 decimal places). Those candidates who did not do as requested usually did not complete the table accurately and therefore usually terminated the algorithm too early.

Question 2 (c)

(c) The inputs remain as $N = 73$ and $A = 8$. The box in the algorithm where B is defined needs adapting to ensure that the negative square root of 73 is the output.
Explain how to adapt the box. **[1]**

It was common for this and the next part to be left blank. Very few candidates realised that all was required here was to change A to $-A$ in the equation $B = \dfrac{\frac{N}{A} + A}{2}$ and this would then ensure that the negative square root of 73 would be the output (with many instead incorrectly suggesting a change to the values of N, A and/or B).

Question 2 (d)

A student claims that if the statement $A > 0$ is removed from the algorithm, so that there is no longer a restriction on the value of A, the algorithm can still be used to find a square root of N.

(d) Explain whether the student's claim is correct. **[1]**

The most common incorrect answer in this part discussed issues with taking the square root of a negative number (which many candidates said would be impossible). Very few candidates realised that the issue here was that if $A = 0$ then B would be undefined.

Question 3 (a)

3 In **Fig. 3** the weights of the arcs represent distances.

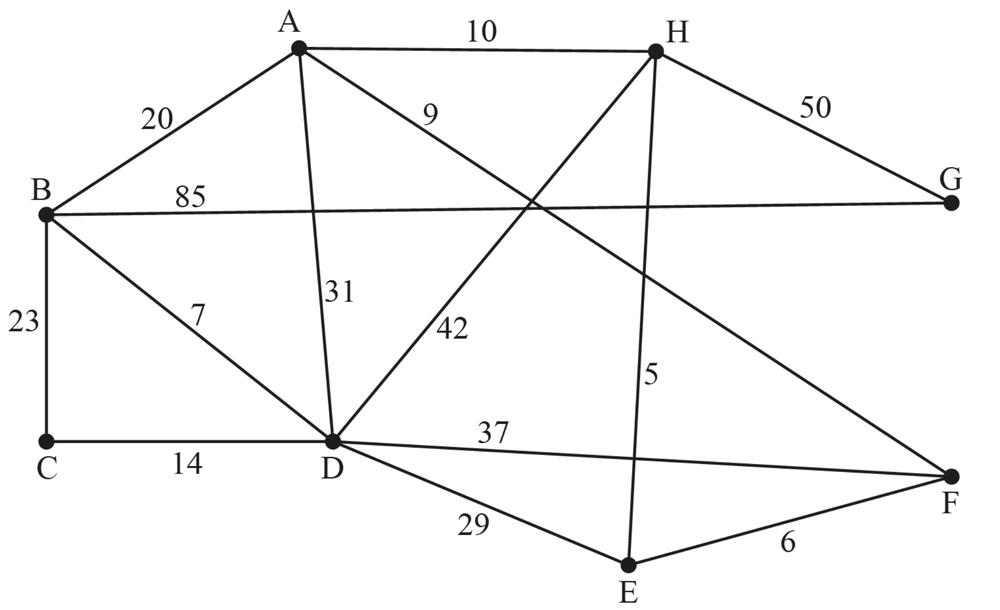


Fig. 3

Dijkstra's algorithm is to be used **once** to find both the shortest path from A to C **and** the shortest path from C to G.

(a) State which vertex should be chosen as the start vertex. **[1]**

Nearly all candidates gave the correct answer here as C (although examiners did note that occasionally candidates gave an answer of A or G).

Question 3 (b) (i)

(b) **(i)** On the copy of the network in the Printed Answer Booklet, apply Dijkstra's algorithm (with the starting vertex stated in part **(a)**) to find both the shortest path from A to C **and** the shortest path from C to G. **[5]**

Many candidates scored full marks in this part. Centres should note that it is vital when applying Dijkstra's algorithm that candidates show all the working values at each node (in this case examiners had to see the correct working values of 23 and 21 at B to indicate that the algorithm was initially being applied correctly) and that the order of labelling is correct (a small number of candidates labelled two different nodes with the same label). It was slightly disappointing that several candidates correctly applied the algorithm but then did not state the shortest routes from A to C and from C to G.

Assessment for learning

The Printed Answer Booklet provided the standard key for the completion of the boxes at each node together with a specific instruction to candidates that they should not cross out their temporary labels. Several candidates still did so. It is vital that examiners can read all the values at each node (so that they can check that the algorithm has been applied correctly) and it is strongly recommended that teachers emphasise that no temporary labels are crossed out in classroom practice.

Question 3 (b) (ii)

(ii) State the weight of the shortest route from A to F via C. **[1]**

Many candidates did not realise that they could use their answer to part (b) to answer this part by simply adding together the final value at A to the final value at F.

Question 3 (c)

(c) Apply Prim's algorithm, starting at A, to find the minimum spanning tree for the network in **Fig. 3**.

- State the order in which the arcs were included in the tree.
- Draw the minimum spanning tree. **[3]**

While most candidates answered this part extremely well many did not follow the specific instruction in the question, which was to state the order in which the arcs were included in the tree and instead they only stated the order in which the nodes were added (or wasted time unnecessarily drawing up a table of values to apply Prim's on). Those candidates who correctly applied Prim's nearly always went on to correctly draw the corresponding tree.

Question 4 (a)

4 **Fig. 4.1** shows an activity network for a project. The arc weights show activity duration in hours.

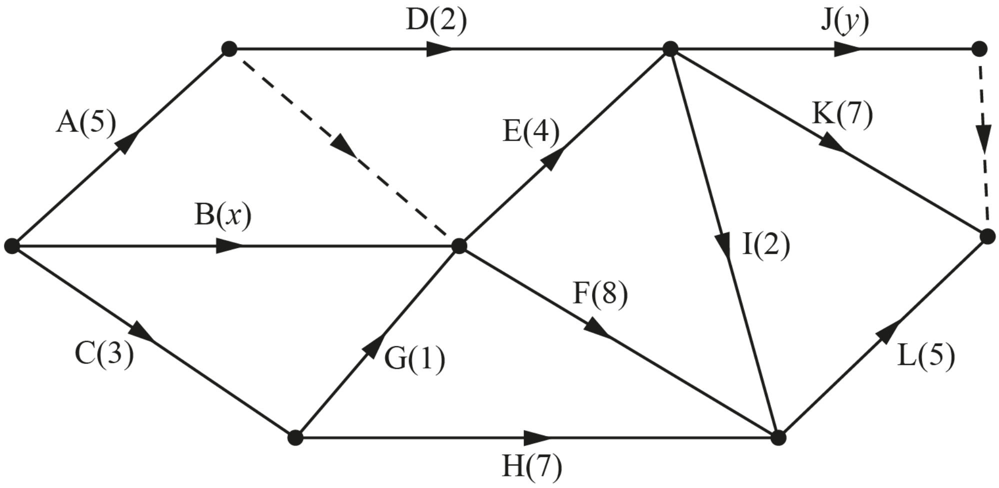


Fig. 4.1

(a) Complete the table in the Printed Answer Booklet to show the immediate predecessors for each activity. **[2]**

This part was answered extremely well with nearly all candidates scoring at least one mark for correctly completing five rows of the table. The most common errors were due to the dummy activities (and so not including A in the immediate predecessors for either E or F).

Question 4 (b)

It is given that the duration of activity B is x hours, and the duration of activity J is y hours where x and y are integers and

$0 < x < 5$ and $0 < y < 7$.

(b) Carry out a forward pass and a backward pass through the entire network to find the following.

- The minimum completion time for the project
- The critical activities **[5]**

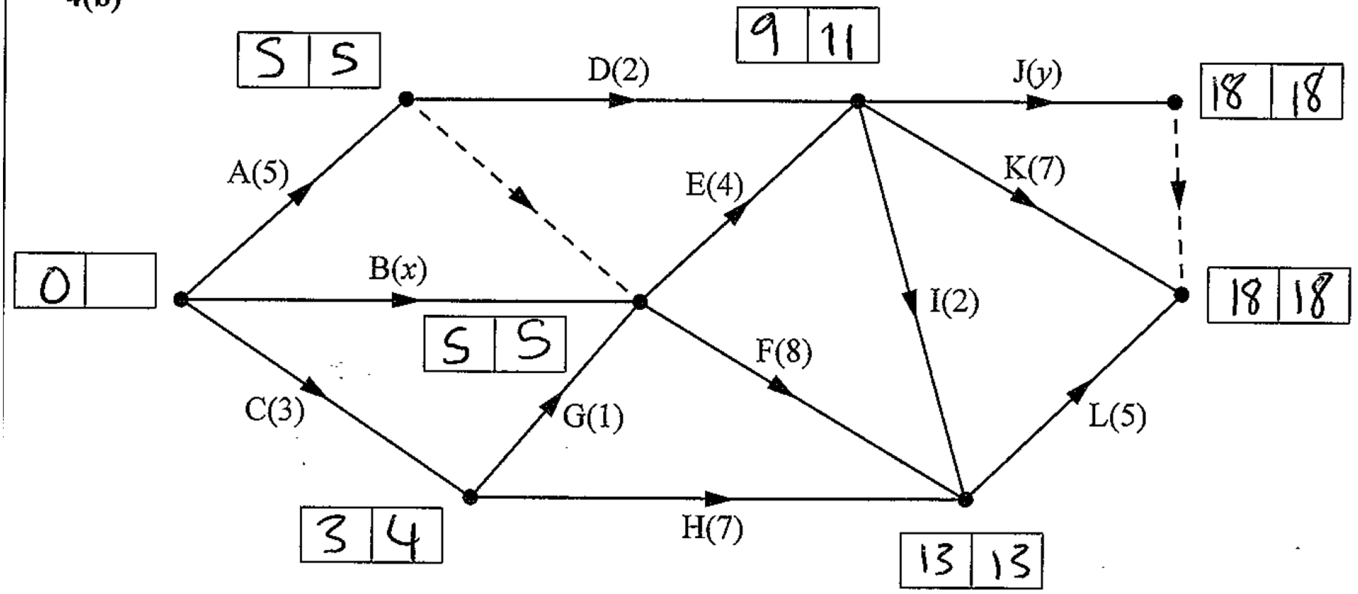
While nearly all candidates managed to score the method marks for attempting both a forward and backward pass through the network it was uncommon to award the corresponding accuracy mark as many candidates did not consider correctly the dummy activities when completing either one or both passes (most notably the backward pass). The most common error though was to leave the forward pass at the end of J either blank or to later replace it with the value found for y when in fact it should have been left as $9 + y$. Most candidates though correctly stated the minimum completion time and critical activities for the project.

Misconception

The start event node should be labelled with a double zero and neither of these two boxes should be left blank.

Exemplar 1

4(b)



Minimum completion time: 18 hours

Critical activities: A F L

This response scored the 2 method marks and the final 2 B marks (for correctly stating the minimum completing time and the critical activities) but did not score the accuracy mark for correctly completing the activity network. This response included the common error of not completing the backward pass (and therefore not having the double zero at the start event) and also the early event time at the end of J is given incorrectly as 18 when in fact it should have been in terms of y.

Question 4 (c)

It is given that the total float for activity J is 4 hours.

(c) Determine the value of y. **[1]**

This part was answered extremely well with most correctly determining the value of y as 5.

Question 4 (d)

Each activity requires one worker.

Fig. 4.2 shows a partly completed resource histogram containing the eight activities A to H in which each of the eight activities begins at their earliest possible start time.

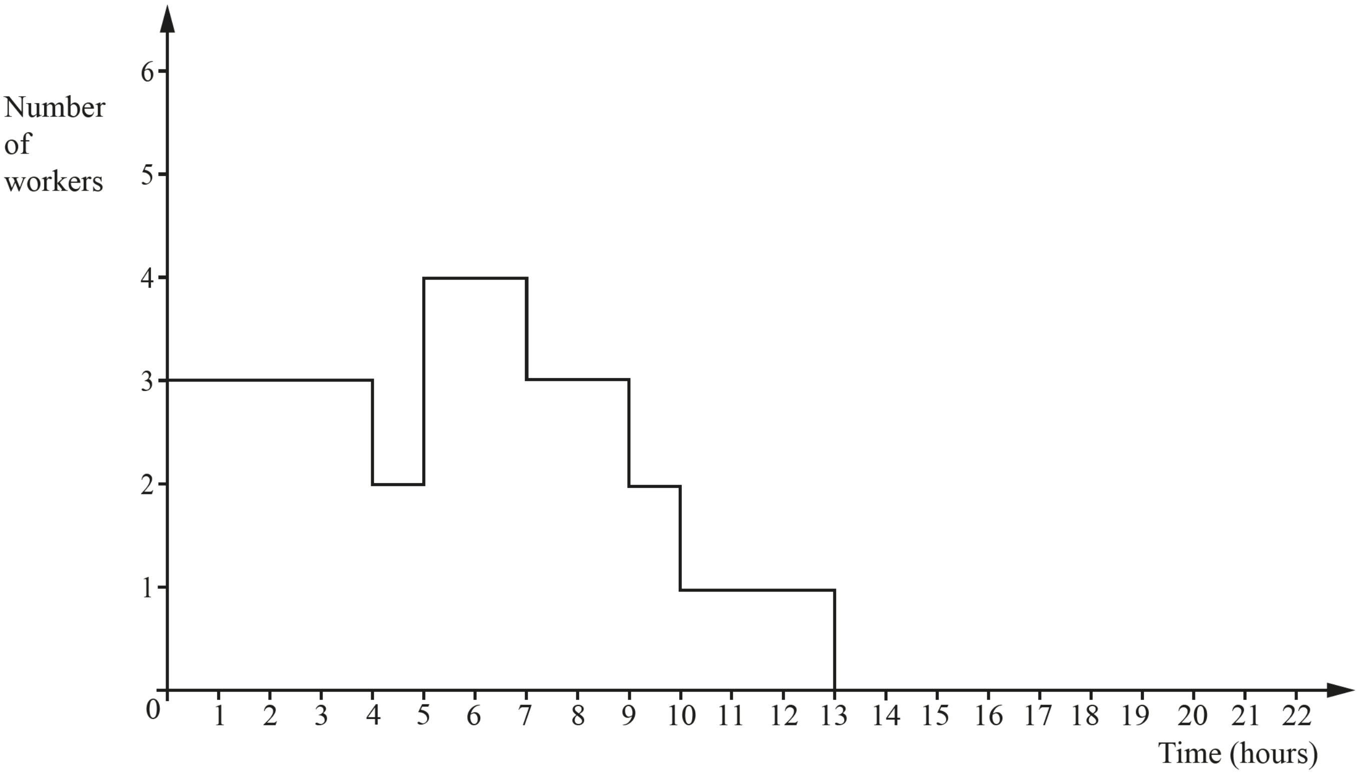


Fig. 4.2

(d) State the value of x. **[1]**

Very few candidates correctly stated the value of x correctly as 3 (with most incorrectly stating the value as 4).

Question 4 (e)

(e) Complete the resource histogram for the project by adding the remaining four activities I, J, K and L to the copy of **Fig. 4.2** in the Printed Answer Booklet.
Each of the four activities should begin at their earliest possible start time. **[2]**

While several candidates left this part blank many also completed the histogram correctly. The most common errors were not realising that 5 workers were needed in the $9 - 10$-time interval and a few candidates had the project finishing later than the completion time found in part (b).

Question 4 (f)

(f) Draw a schedule to show how three workers can complete the project in the minimum completion time. Each box in the Printed Answer Booklet represents 1 hour.
For each worker, write the letter of the activity they are doing in each box, or leave the box blank if the worker is not required for that 1 hour. **[2]**

This part was answered extremely well with many candidates scoring at least one mark for producing a schedule that used at most three workers, with at least 10 activities placed of which 5 were correct. When errors occurred, it was usually due to precedence issues and candidates are reminded that after completing such a schedule it is wise to check that each activity has the correct duration, is taking place in the correct time interval and that precedence with other activities has been maintained (candidates should be reminded that the activity network diagram with the forward and backward passes it extremely useful in completing an accurate schedule of workers to tasks).

Question 5 (a) (i)

5 **Fig. 5.1** represents a system of pipes through which a fluid flows continuously from a source S to a sink T. The weight on the arcs show the capacities of the pipes in litres per minute.

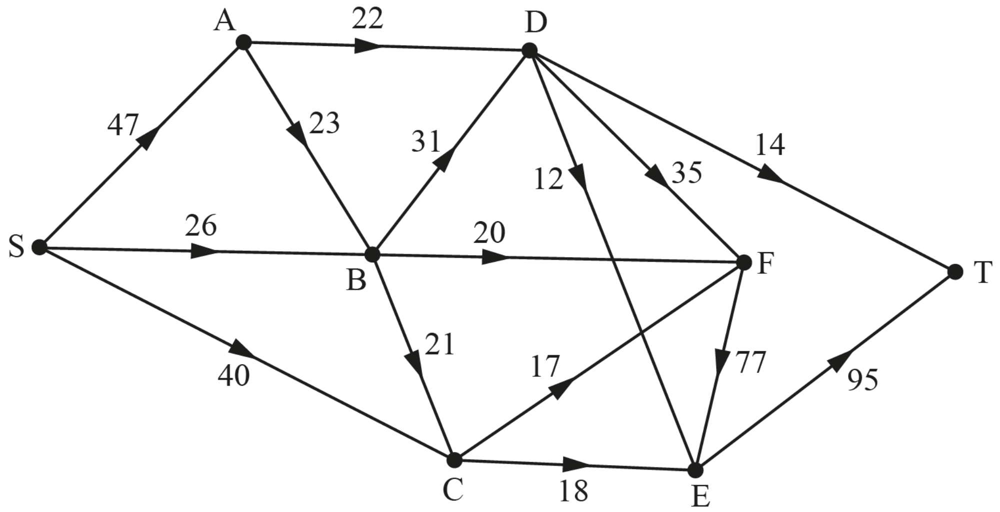


Fig. 5.1

(a) **(i)** The cut α partitions the vertices into the sets $\{S, A\}, \{B, C, D, E, F, T\}$.

Calculate the capacity of cut α. **[1]**

This part was answered extremely well by most candidates with nearly all giving the correct answer of 111.

Question 5 (a) (ii)

(ii) The cut β partitions the vertices into the sets $\{S, A, C, E\}, \{B, D, F, T\}$.

Calculate the capacity of cut β. **[1]**

Although not as well answered as (i) (due to arc BC flowing from sink to source) many candidates still gave the correct answer of 183.

Question 5 (b)

(b) Using only the capacities of cuts α and β, explain what can be deduced about the maximum possible flow through the system. **[1]**

Almost all candidates correctly inferred that the maximum possible flow was at most the least of the two values found in part (a).

Question 5 (c)

An LP formulation is set up to find the maximum flow through the network.

(c) Explain why a possible objective function for the LP formulation is to maximise SA + SB + CE + CF. **[1]**

The most common correct answer seen by examiners was to state that the given arcs form a cut (and therefore form a possible objective function for the LP formulation). The second most common correct answer was to infer that as all the flow from SC must pass through arcs CE and CF the objective of maximising the flow from the source (SA + SB + SC) is equivalent to maximising SA + SB + CE + CF.

Question 5 (d)

(d) Write down the required constraint in the LP formulation regarding the flow through vertex F. **[1]**

This part was answered extremely well although some candidates did not realise the subtle difference in an LP formulation between the correct answer of DF + BF + CF – FE = 0 and the incorrect answer of DF + BF + CF – EF = 0.

Misconception

? In any LP formulation concerning directed arcs it is vital that the order in which the letters are used is correct. Many candidates had no hesitation in using EF even though in this context it had to be stated as FE (as the flow could only be from F to E).

Question 5 (e)

The LP formulation for the network was run in a solver and some of the output is shown in **Fig. 5.2**.

Variable	Value
SA	45.000 000
SC	35.000 000
BC	0.000 000
BD	31.000 000
DT	11.000 000
ET	95.000 000
FE	70.000 000

Fig. 5.2

(e) Explain how the output in **Fig. 5.2** gives a flow of 106 litres per minute through the system of pipes. **[1]**

This part was answered extremely well with almost all candidates correctly stating that the flow of 106 came from summing the values of 11 and 95 (from DT and ET respectively) from Fig. 5.2.

Question 5 (f)

(f) Use the diagram in the Printed Answer Booklet to show how a flow of 106 litres per minute can be achieved. **[2]**

The most common misunderstanding in this part was by some candidates who only showed the flow in one particular path from S to T rather than the flow through the entire network (subject to the conditions given in the question). There are two main points that candidates must consider when tackling this type of question. They are the feasibility condition (which says that the flow along each arc must not exceed the capacity of that arc) and the conservation condition (which says that apart from the source (S) and sink (T) nodes the total flow into a node must equal the total flow out of that node).

Misconception

An arc that has no flow passing through it, such as BC in this part, should be labelled with a 0 and not simply left blank..

Question 5 (g)

(g) Use a suitable cut to show that a flow of 106 litres per minute is the maximum possible flow through the system of pipes. **[2]**

It was extremely rare for candidates to either state a correct cut with capacity 106 or for them to give enough detail in proving that this flow was indeed maximal.

Assessment for learning

Proving a flow is maximal:

Step 1: state a cut, based on the capacity of saturated arcs directed from source to sink and arcs with zero flow directed from sink to source, as either a set of nodes or as a list of arcs which the cut passes through, and conclude that therefore the minimum cut is less than or equal to this value.

Step 2: state the value of the current flow through the network and conclude that therefore the maximum flow is greater than or equal to this value.

Step 3: if these two values are the same then by the maximum flow-minimum cut theorem a maximum flow for the network has been found.

Misconception

When calculating the capacity of a cut candidates must use the capacity of the arcs and not the current flow which is passing through those arcs (otherwise all cuts for the network would have the same capacity!).

Question 6 (a)

6 Each Monday morning a company has its weekly delivery of milk.
The milk comes in three types, whole, semi-skimmed and skimmed.

The company manager knows that each week she should order the following.

- At most 32 litres in total of semi-skimmed and skimmed milk.
- At least three times as much semi-skimmed milk as skimmed milk.

Furthermore, at least 10% of the milk should be skimmed milk.

The cost of one litre of whole milk is 55p, the cost of one litre of semi-skimmed milk is 50p, and the cost of one litre of skimmed milk is 40p.

In total the company has a budget of £50 to spend each week on milk.

Let x represent the number of litres of whole milk.
Let y represent the number of litres of semi-skimmed milk.
Let z represent the number of litres of skimmed milk.

The company manager wants to maximise the total amount of milk ordered each week.

(a)

- Complete the initial tableau in the Printed Answer Booklet so that the simplex method may be used to solve this problem.
- Show how the constraints for the problem have been made into equations using slack variables. **[7]**

It is vital in questions like this that the candidate reads the entire question carefully before beginning as several candidates only completed the initial tableau and did not show the constraints (as equations). Most candidates could correctly deal with the constraints regarding the 32 litres, at least 10% of the milk being skimmed and the budget available. However, it was the constraint regarding 'at least three times as much semi-skimmed as skimmed' that candidates found the most difficult with only the most able correctly stating this as $y \geqslant 3z$ (and then being able to convert this to an equation using a slack variable).

Assessment for learning

Candidates are reminded that when filling in an initial tableau that all cells must be completed (especially zeros).

Exemplar 2

6(a)

Maximise : $x + y + z$

ST:

$y + z \leqslant 32$

$3y \leqslant z$

$\frac{1}{10}(x + y + z) \leqslant y$

$0.55x + 0.5y + 0.4z \leqslant 50$

Maximise:

B1 $P - x - y - z = 0$

ST:

M1 $y + z + s_1 = 32$

A1 $3y - z + s_2 = 0$

A0 $\frac{1}{10}x - \frac{9}{10}y + \frac{1}{10}z + s_3 = 0$

$0.55x + 0.5y + 0.4z + s_4 = 50$

A0

s_1, s_2, s_3, s_4 are all slack variables

P	x	y	z	s_1	s_2	s_3	s_4	RHS
1	−1	−1	−1	0	0	0	0	0
0	0	1	1	1	0	0	0	32
0	0	3	−1	0	1	0	0	0
0	$\frac{1}{10}$	$-\frac{9}{10}$	$\frac{1}{10}$	0	0	1	0	0
0	0.55	0.5	0.4	0	0	0	1	50

M1

A0

This response scored 4 of the 7 marks available in this part. The candidate correctly stated the objective function and dealt with the two constraints regarding at most 32 litres in total being semi-skimmed and skimmed, and the total budget being at most £50. However, they clearly misread the constraint regarding 'at least 10% of the milk being skimmed' as being semi-skimmed (as here they used *y* instead of z in the RHS of $\frac{1}{10}(x+y+z) \leqslant z$) and they could not deal with the 'at least three times as much semi-skimmed as skimmed' constraint as they incorrectly stated that $3y \leqslant z$ instead of $y \geqslant 3z$ (as noted earlier this was a very common error).

Question 6 (b) (i)

After two iterations of the simplex method a computer produces the tableau below.

P	x	y	z	s_1	s_2	s_3	s_4	RHS
1	0	$-\frac{10}{3}$	0	0	$\frac{10}{3}$	1	0	0
0	0	$\frac{4}{3}$	0	1	$-\frac{1}{3}$	0	0	32
0	0	$-\frac{1}{3}$	1	0	$\frac{1}{3}$	0	0	0
0	1	-2	0	0	3	1	0	0
0	0	$\frac{104}{3}$	0	0	$-\frac{107}{3}$	-11	1	1000

(b) (i) Perform a third iteration of the simplex method. **[3]**

Candidates overall were very proficient in carrying out the simplex method and many identified the correct pivot value (the 4/3 in the second row) and used this to carry out the third iteration as requested. The most common errors were sign errors on certain values or difficulty in dealing with fractions. There were a significant minority who pivoting on an incorrect value and some who even used a negative value as a pivot.

Question 6 (b) (ii)

(ii) Explain how the answer to part **(b)(i)** shows that the solution obtained after the third iteration is optimal. **[1]**

Almost all candidates correctly stated that as there were no negative values in the objective row then the solution obtained after the third iteration was indeed optimal.

Question 6 (c) (i)

(c) **(i)** State the number of litres of each type of milk the company manager should order each week. **[1]**

Almost all candidates who had correctly obtained the correct RHS column in part (b) correctly stated (in context) the number of litres of each type of milk required.

Question 6 (c) (ii)

(ii) Calculate how much of the weekly milk budget will not be spent. **[1]**

This part was answered extremely well with many stating the correct value.

Question 6 (d)

Due to an increase in the amount of milk consumed, the manager believes that it may be possible, with a weekly budget of **at least** £50, to order exactly 40 litres in total of semi-skimmed and skimmed milk each week.

She still plans on ordering at least three times as much semi-skimmed milk as skimmed milk, and that at least 10% of the milk ordered should still be skimmed.

Furthermore, she still wishes to maximise the total amount of milk ordered each week.

(d) The two-stage simplex method is to be used to solve this modified problem.

- Formulate the modified constraints as equations.
- Define the new objective function.

In both cases, you are required to define the variables you use. Note that you do not need to re-state the original objective function or any constraints that are unchanged. **[4]**

Candidates found this part very demanding with very few realising that they had to re-write the constraint $y+z=40$ as $y+z \leqslant 40$ and $y+z \geqslant 40$, and then add slack, surplus and artificial variables as required. The change to the budget constraint required the addition of a surplus and artificial variable to the corresponding equation and so the new objective Q was therefore the sum of two artificial variables (with many candidates only having one such variable as the new objective). Even though the question asked candidates to define the variables they used very few did (with only the most able defining the new objective as one that needed to be minimised).

Exemplar 3

6(d)

1 $55x + 50y + 40z \geq 5000$

$11x + 10y + 8z \geq 1000$

2 $y + z = 40$

$\Rightarrow y+z \leq 40, \; y+z \geq 40$

3 $3z - y \leq 0$

4 $x + y - 9z \leq 0$

$11x + 10y + 8z \geq 1000 \Rightarrow \cancel{11x + 10y + 8z - s_1 + a_1}$

$\Rightarrow 11x + 10y + 8z - s_5 + a_1 = 1000$

$y + z \leq 40 \Rightarrow y + z + s_1 = 40$

$y + z \geq 40 \Rightarrow y + z - s_6 + a_2 = 40$

Let $Q = a_1 + a_2$

$$\begin{array}{r} 11x + 10y + 8z - s_5 + a_1 = 1000 \\ + \quad y + z - s_6 + a_2 = 40 \\ \hline Q + 11x + 11y + 9z - s_5 - s_6 = 1040 \end{array}$$

Minimise $Q + 11x + 11y + 9z - s_5 + s_6 = 1040$

$\Downarrow$

New objective function.

Slack variable:

$s_1 \geq 0$

Surplus variables:

$s_5 \geq 0, \; s_6 \geq 0$

artificial variables:

$a_1 \geq 0, \; a_2 \geq 0$

This response scored all 4 marks available in this part. The candidate has correctly rewritten the equality constraint $y + z = 40$ using two inequalities and has correctly dealt with the change to the budget constraint. Note that the candidate has correctly introduced a new objective function Q (which is the sum of the two artificial variables) and has also correctly defined all variables used at the end of their response.

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