



GCE

Further Mathematics B (MEI)

Y413/01: Modelling with algorithms

Advanced Subsidiary GCE

Mark Scheme for June 2019

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This mark scheme is published as an aid to teachers and students, to indicate the requirements of the examination. It shows the basis on which marks were awarded by examiners. It does not indicate the details of the discussions which took place at an examiners' meeting before marking commenced.

All examiners are instructed that alternative correct answers and unexpected approaches in candidates' scripts must be given marks that fairly reflect the relevant knowledge and skills demonstrated.

Mark schemes should be read in conjunction with the published question papers and the report on the examination.

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Annotations and abbreviations

| Annotation in scoris | Meaning |
|---|---|
| ✓ and ✕ | |
| BOD | Benefit of doubt |
| FT | Follow through |
| ISW | Ignore subsequent working |
| M0, M1 | Method mark awarded 0, 1 |
| A0, A1 | Accuracy mark awarded 0, 1 |
| B0, B1 | Independent mark awarded 0, 1 |
| SC | Special case |
| ^ | Omission sign |
| MR | Misread |
| Highlighting | |
| | |
| Other abbreviations in mark scheme | Meaning |
| E1 | Mark for explaining a result or establishing a given result |
| dep* | Mark dependent on a previous mark, indicated by * |
| cao | Correct answer only |
| oe | Or equivalent |
| rot | Rounded or truncated |
| soi | Seen or implied |
| www | Without wrong working |
| AG | Answer given |
| awrt | Anything which rounds to |
| BC | By Calculator |
| DR | This indicates that the instruction In this question you must show detailed reasoning appears in the question. |

Subject-specific Marking Instructions for A Level Mathematics B (MEI)

- a Annotations should be used whenever appropriate during your marking. The A, M and B annotations must be used on your standardisation scripts for responses that are not awarded either 0 or full marks. It is vital that you annotate standardisation scripts fully to show how the marks have been awarded. For subsequent marking you must make it clear how you have arrived at the mark you have awarded.
- b An element of professional judgement is required in the marking of any written paper. Remember that the mark scheme is designed to assist in marking incorrect solutions. Correct solutions leading to correct answers are awarded full marks but work must not be judged on the answer alone, and answers that are given in the question, especially, must be validly obtained; key steps in the working must always be looked at and anything unfamiliar must be investigated thoroughly. Correct but unfamiliar or unexpected methods are often signalled by a correct result following an apparently incorrect method. Such work must be carefully assessed. When a candidate adopts a method which does not correspond to the mark scheme, escalate the question to your Team Leader who will decide on a course of action with the Principal Examiner. If you are in any doubt whatsoever you should contact your Team Leader.
- c The following types of marks are available.

M

A suitable method has been selected and *applied* in a manner which shows that the method is essentially understood. Method marks are not usually lost for numerical errors, algebraic slips or errors in units. However, it is not usually sufficient for a candidate just to indicate an intention of using some method or just to quote a formula; the formula or idea must be applied to the specific problem in hand, e.g. by substituting the relevant quantities into the formula. In some cases the nature of the errors allowed for the award of an M mark may be specified.

A

Accuracy mark, awarded for a correct answer or intermediate step correctly obtained. Accuracy marks cannot be given unless the associated Method mark is earned (or implied). Therefore M0 A1 cannot ever be awarded.

B

Mark for a correct result or statement independent of Method marks.

E

A given result is to be established or a result has to be explained. This usually requires more working or explanation than the establishment of an unknown result.

Unless otherwise indicated, marks once gained cannot subsequently be lost, e.g. wrong working following a correct form of answer is ignored. Sometimes this is reinforced in the mark scheme by the abbreviation isw. However, this would not apply to a case where a candidate passes through the correct answer as part of a wrong argument.

- d When a part of a question has two or more 'method' steps, the M marks are in principle independent unless the scheme specifically says otherwise; and similarly where there are several B marks allocated. (The notation 'dep*' is used to indicate that a particular mark is dependent on an earlier, asterisked, mark in the scheme.) Of course, in practice it may happen that when a candidate has once gone wrong in a part of a question, the work from there on is worthless so that no more marks can sensibly be given. On the other hand, when two or more steps are successfully run together by the candidate, the earlier marks are implied and full credit must be given.
- e The abbreviation FT implies that the A or B mark indicated is allowed for work correctly following on from previously incorrect results. Otherwise, A and B marks are given for correct work only – differences in notation are of course permitted. A (accuracy) marks are not given for answers obtained from incorrect working. When A or B marks are awarded for work at an intermediate stage of a solution, there may be various alternatives that are equally acceptable. In such cases, what is acceptable will be detailed in the mark scheme. If this is not the case please, escalate the question to your Team Leader who will decide on a course of action with the Principal Examiner.
Sometimes the answer to one part of a question is used in a later part of the same question. In this case, A marks will often be 'follow through'. In such cases you must ensure that you refer back to the answer of the previous part question even if this is not shown within the image zone. You may find it easier to mark follow through questions candidate-by-candidate rather than question-by-question.
- f Unless units are specifically requested, there is no penalty for wrong or missing units as long as the answer is numerically correct and expressed either in SI or in the units of the question. (e.g. lengths will be assumed to be in metres unless in a particular question all the lengths are in km, when this would be assumed to be the unspecified unit.) We are usually quite flexible about the accuracy to which the final answer is expressed; over-specification is usually only penalised where the scheme explicitly says so. When a value is given in the paper only accept an answer correct to at least as many significant figures as the given value. This rule should be applied to each case. When a value is not given in the paper accept any answer that agrees with the correct value to 2 s.f. Follow through should be used so that only one mark is lost for each distinct accuracy error, except for errors due to premature approximation which should be penalised only once in the examination. There is no penalty for using a wrong value for *g*. E marks will be lost except when results agree to the accuracy required in the question.
- g Rules for replaced work: if a candidate attempts a question more than once, and indicates which attempt he/she wishes to be marked, then examiners should do as the candidate requests; if there are two or more attempts at a question which have not been crossed out, examiners should mark what appears to be the last (complete) attempt and ignore the others. NB Follow these maths-specific instructions rather than those in the assessor handbook.
- h For a genuine misreading (of numbers or symbols) which is such that the object and the difficulty of the question remain unaltered, mark according to the scheme but following through from the candidate's data. A penalty is then applied; 1 mark is generally appropriate, though this may differ for some units. This is achieved by withholding one A mark in the question. Marks designated as cao may be awarded as long as there are no other errors. E marks are lost unless, by chance, the given results are established by equivalent working. 'Fresh starts' will not affect an earlier decision about a misread. Note that a miscopy of the candidate's own working is not a misread but an accuracy error.
- i If a graphical calculator is used, some answers may be obtained with little or no working visible. Allow full marks for correct answers (provided, of course, that there is nothing in the wording of the question specifying that analytical methods are required). Where an answer is wrong but there is some evidence of method, allow appropriate method marks. Wrong answers with no supporting method score zero. If in doubt, consult your Team Leader.
- j If in any case the scheme operates with considerable unfairness consult your Team Leader.

| Question | | Answer | Marks | AOs | Guidance |
|----------|-----|--|---|--|---|
| 1 | (a) | Bin 1: 24 17 9 Bin 2: 25 18 Bin 3: 11 23 15 Bin 4: 19 30 | M1 A1 [2] | 1.1 1.1 | First six numbers placed correctly (those in bold) cao (no additional/repeated values) |
| 1 | (b) | <u>24</u> 17 9 25 18 11 23 19 30 15 <u>25</u> 30 24 <u>17</u> 9 18 11 23 19 15 (1 st pass) 30 25 24 <u>18</u> 23 19 17 <u>9</u> 11 15 (2 nd pass) 30 25 24 <u>23</u> 19 18 17 <u>11</u> 15 9 (3 rd pass) 30 25 24 23 19 18 17 15 11 9 (4 th pass) All sublists have only one element so sort is complete | M1 A1 A1 [3] | 1.1 1.1 1.1 | 24 used as the first pivot and in the correct position after the first pass First three passes correct – must be using quick (not slow) sort Correct sort with either a fifth pass in which no changes are made or an indication that the sort is complete after a fourth pass Mark ascending as a misread |
| 1 | (c) | Bin 1: 30 19 Bin 2: 25 24 Bin 3: 23 18 9 Bin 4: 17 15 11 | M1 A1 [2] | 1.1 1.1 | First six numbers placed correctly (those in bold) cao (no additional/repeated values) |

| Question | | Answer | | Marks | AOs | Guidance | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------|--------------------------|---|----------|--------------------------|------------|--|---|---|---|---|---|---|---|---|---|---------|---|---------|---|---|---|------------|---|------|---|---|---|------|--|---------------------------------------|------------------------------|--|
| 1 | (d) | For both algorithms the worst case is that each number that has to be placed into a bin will not fit in any of the previous bins and so therefore each new number has to be compared with the spare capacity of all previous bins before being placed in a separate bin. The fact that the numbers are either in decreasing order or not does not change this fact (regarding the required comparisons) and so both algorithms have the same order of complexity | | B1 [1] | 2.4 | For both algorithms (in the worst case) each number has to be compared with all previous numbers/bins (before being placed into a new bin) | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | (a) | <table border="1"> <thead> <tr> <th>Activity</th> <th>Immediate Predecessor(s)</th> </tr> </thead> <tbody> <tr><td>A</td><td>-</td></tr> <tr><td>B</td><td>-</td></tr> <tr><td>C</td><td>-</td></tr> <tr><td>D</td><td>C</td></tr> <tr><td>E</td><td>A</td></tr> <tr><td>F</td><td>A, B, D</td></tr> <tr><td>G</td><td>A, B, D</td></tr> <tr><td>H</td><td>C</td></tr> <tr><td>I</td><td>E, F, G, H</td></tr> <tr><td>J</td><td>G, H</td></tr> <tr><td>K</td><td>I</td></tr> <tr><td>L</td><td>I, J</td></tr> </tbody> </table> | Activity | Immediate Predecessor(s) | A | - | B | - | C | - | D | C | E | A | F | A, B, D | G | A, B, D | H | C | I | E, F, G, H | J | G, H | K | I | L | I, J | | B1 B1 [2] | 1.1 1.1 | Any 5 rows correct (not including rows A, B, C) cao |
| Activity | Immediate Predecessor(s) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A | - | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| B | - | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C | - | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D | C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F | A, B, D | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G | A, B, D | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | C | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| I | E, F, G, H | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| J | G, H | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| K | I | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| L | I, J | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Question | Answer | Marks | AOs | Guidance |
|-------------------|---|--|---|---|
| <p>2 (b)</p> | <p>Any critical activity must be part of a critical path from source to sink. If E is critical then this guarantees that A and I must be critical (as E depends on the completion of A only and only activity I requires the immediate completion of activity E)</p> <p>However K does not necessarily have to be critical as the critical path which goes through E could be AEIL (if the duration of activity L is greater than the duration of activity K) and so the manager’s claim is not necessarily correct</p> | <p>B1</p> <p>B1</p> <p>[2]</p> | <p>3.1b</p> <p>2.2b</p> | <p>A and I are critical or comment that every activity (on a critical path) has to be critical</p> <p>Mention that either K or L is critical</p> <p>For B2 allow mention that a critical path for the network could be either AEIK or AEIL</p> |
| <p>2 (c) (i)</p> | | <p>M1</p> <p>A1</p> <p>M1</p> <p>A1</p> <p>[4]</p> | <p>1.1</p> <p>1.1</p> <p>1.1</p> <p>1.1</p> | <p>Forward pass – numbers increasing from source to sink (allow one slip) cao for forward pass</p> <p>Backward pass – numbers decreasing from sink to source (allow one slip) cao for backward pass</p> |
| <p>2 (c) (ii)</p> | <p>27 hours</p> | <p>B1</p> <p>[1]</p> | <p>2.2a</p> | |

| Question | Answer | Marks | AOs | Guidance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| 2 (e) | The manager’s claim is incorrect because e.g. the total duration of all the activities is 64 hours and with a minimum completion time of 27 hours this would require $64/27 = 2.37\dots$ workers so 3 workers is the minimum required | B1 [1] | 2.4 | Or other valid reason e.g. the sum of the durations for non-critical activities is 37 hours which is greater than 27 OR activities B, C, D and F take 18 hours, but these need to be completed in 17 hours to avoid delaying activity I – if detailing when activities must be completed by (oe) then mention of both activities and times must be given | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 (a) | <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>1</th> <th>2</th> <th>3</th> <th>8</th> <th>7</th> <th>4</th> <th>6</th> <th>5</th> <th>9</th> </tr> <tr> <th></th> <th>A</th> <th>B</th> <th>C</th> <th>D</th> <th>E</th> <th>F</th> <th>G</th> <th>H</th> <th>I</th> </tr> </thead> <tbody> <tr> <th>A</th> <td></td> <td>5</td> <td>8</td> <td>16</td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <th>B</th> <td>5</td> <td></td> <td>2</td> <td></td> <td></td> <td>4</td> <td>11</td> <td></td> <td></td> </tr> <tr> <th>C</th> <td>8</td> <td>2</td> <td></td> <td>8</td> <td></td> <td>1</td> <td></td> <td></td> <td></td> </tr> <tr> <th>D</th> <td>16</td> <td></td> <td>8</td> <td></td> <td>2</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <th>E</th> <td></td> <td></td> <td></td> <td>2</td> <td></td> <td>3</td> <td></td> <td></td> <td>5</td> </tr> <tr> <th>F</th> <td></td> <td>4</td> <td>1</td> <td></td> <td>3</td> <td></td> <td></td> <td>2</td> <td>12</td> </tr> <tr> <th>G</th> <td></td> <td>11</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>2</td> <td></td> </tr> <tr> <th>H</th> <td></td> <td></td> <td></td> <td></td> <td></td> <td>2</td> <td>2</td> <td></td> <td>7</td> </tr> <tr> <th>I</th> <td></td> <td></td> <td></td> <td></td> <td>5</td> <td>12</td> <td></td> <td>7</td> <td></td> </tr> </tbody> </table> <p>AB, BC, CF, FH, GH, EF, DE, EI</p> <p>Total length of MST = 22</p> | | 1 | 2 | 3 | 8 | 7 | 4 | 6 | 5 | 9 | | A | B | C | D | E | F | G | H | I | A | | 5 | 8 | 16 | | | | | | B | 5 | | 2 | | | 4 | 11 | | | C | 8 | 2 | | 8 | | 1 | | | | D | 16 | | 8 | | 2 | | | | | E | | | | 2 | | 3 | | | 5 | F | | 4 | 1 | | 3 | | | 2 | 12 | G | | 11 | | | | | | 2 | | H | | | | | | 2 | 2 | | 7 | I | | | | | 5 | 12 | | 7 | | M1 A1 B1 B1 [4] | 1.1 1.1 1.1 | Choosing the 5 in column A, the 2 in column B and the 1 in column C (or 1, 2, 3, -, -, 4, -, -, - across the top of the table or A, B, C, F,... or AB, BC, CF,...) All circled values correct (or all numbers correct across the top of the table) |
| | 1 | 2 | 3 | 8 | 7 | 4 | 6 | 5 | 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | A | B | C | D | E | F | G | H | I | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| A | | 5 | 8 | 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| B | 5 | | 2 | | | 4 | 11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| C | 8 | 2 | | 8 | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| D | 16 | | 8 | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | | | | 2 | | 3 | | | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| F | | 4 | 1 | | 3 | | | 2 | 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G | | 11 | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| H | | | | | | 2 | 2 | | 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| I | | | | | 5 | 12 | | 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Question | | Answer | | | | Marks | AOs | Guidance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-------------------------------------|-----|--|--------------------|--------|----------------|-----------------|--------------------|---|----------------|---|---|---|-----|---|---|---|---|---|---|---|-----|---|---|----|----------|---|---|----|----|---|---|---|-----|---|---|----|-------|---|---|----|----|---|---|----|----------|-----------------------------------|-----------------------------------|---|
| 3 | (b) | <table border="1"> <thead> <tr> <th>Node</th> <th>Order of labelling</th> <th>labels</th> <th>Working values</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>1</td> <td>0</td> <td>(0)</td> </tr> <tr> <td>B</td> <td>2</td> <td>5</td> <td>5</td> </tr> <tr> <td>C</td> <td>3</td> <td>7</td> <td>8 7</td> </tr> <tr> <td>D</td> <td>8</td> <td>13</td> <td>16 15 13</td> </tr> <tr> <td>E</td> <td>6</td> <td>11</td> <td>11</td> </tr> <tr> <td>F</td> <td>4</td> <td>8</td> <td>9 8</td> </tr> <tr> <td>G</td> <td>7</td> <td>12</td> <td>16 12</td> </tr> <tr> <td>H</td> <td>5</td> <td>10</td> <td>10</td> </tr> <tr> <td>I</td> <td>9</td> <td>16</td> <td>20 17 16</td> </tr> </tbody> </table> | | | | Node | Order of labelling | labels | Working values | A | 1 | 0 | (0) | B | 2 | 5 | 5 | C | 3 | 7 | 8 7 | D | 8 | 13 | 16 15 13 | E | 6 | 11 | 11 | F | 4 | 8 | 9 8 | G | 7 | 12 | 16 12 | H | 5 | 10 | 10 | I | 9 | 16 | 20 17 16 | M1 A1 A1 A1 B1 [5] | 1.2 1.1a 1.1a 1.1 1.1 | Correct working values at C Working values Labels Order of labelling |
| | | Node | Order of labelling | labels | Working values | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | A | 1 | 0 | (0) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | B | 2 | 5 | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | C | 3 | 7 | 8 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | D | 8 | 13 | 16 15 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | E | 6 | 11 | 11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | F | 4 | 8 | 9 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | G | 7 | 12 | 16 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | H | 5 | 10 | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| I | 9 | 16 | 20 17 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Shortest route from A to I = ABCFEI | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | (c) | 7 + 12 = 19 | | | | B1ft [1] | 3.4 | Their final value at C + their final value at G | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | (a) | A supersource labelled S with arcs SA, SB and SC with the following weight (or greater): SA = 17, SB = 59, SC = 55 with arrows | | | | B1 B1 [2] | 1.1 1.1 | If B0 B0 then SC B1 for arrows or weights correct but must only have the correct 5 arcs | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | A supersink labelled T with arcs GT and HT with the following weights (or greater): GT = 53 and HT = 62 with arrows | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Question | | | Answer | Marks | AOs | Guidance |
|----------|-----|------|---|--|-------------------------------|---|
| 4 | (b) | | Cut = 24 + 53 + 40 + 20 + 30 = 167 (gallons per hour) | B1 [1] | 2.2a | |
| 4 | (c) | (i) | Arcs AE, BD, BE, BI, CE and FI form a cut in the network This line of the formulation therefore maximises the total flow in the network, so finds the capacity | B1* Dep*B1 [2] | 1.1 3.3 | Must mention these arcs form a cut or that all the flow for the network passes through these arcs Award B1B0 for an explanation that implies that these arcs will maximise the total flow in the network with some mention of the inclusion of FI |
| 4 | (c) | (ii) | The total flow into each node must be equal to the total flow out of each node (excluding the source and sink). The only arc leading into D is BD and the only arc out of D is DH and hence $BD - DH = 0$ | B1 [1] | 2.5 | Explains that flow into D = flow out of D (must mention D) |
| 4 | (d) | | $AE + BE + CE + IE - EG - EH = 0$, $BI + FI - IE = 0$ $AE \leq 17, DH \leq 22, EG \leq 53, EH \leq 40, FI \leq 27, IE \leq 18$ | B1 B1 [2] | 3.3 3.3 | Not $EA + EB + \dots$ Condone additional constraints |
| 4 | (e) | (i) | 97 (gallons per hour) | B1 [1] | 3.4 | |
| 4 | (e) | (ii) | The capacity of the cut which partitions the vertices into the sets {S, A, B, C, D, F, I}, {E, G, H, T} is $22 + 17 + 15 + 25 + 18 = 97 \therefore \text{min. cut} \leq 97$ By the maximum flow-minimum cut theorem the maximum flow is equal to the minimum cut and so therefore the maximum flow through the system is 97 gallons per hour | B1* Dep*B1 [2] | 3.1b 2.1 | Condone without S and/or T - allow listing of cut arcs (DH, AE, BE, CE, IE) Requires correct cut, 97 stated and mention of max flow-min cut theorem |

| Question | | | Answer | Marks | AOs | Guidance | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|----------|-----|------|---|---|--|--|-------|-------|-------|-------|-------|-------|-------|-------|-----|---|---|---|---|---|----|---|---|----|---|---|----|---|---|----|----|----|---|---|---|---|---|---|---|---|---|---|---|---|----|---|---|---|---|---|----|---|---|---|---|---|---|---|---|---|---|---|----|---|---|---|---|----|---|---|---|---|---|---|----|---|---|---|---|----|---|---|---|----|---|---|----|--|--|--|
| 4 | (f) | (i) | No effect as all the pipes leading into E are already saturated so no more flow can be sent through E (even if the capacity of E is increased) | B1 [1] | 3.5a | No effect (oe) + explanation (pipes into E are already saturated or EH is not saturated before the increase of 20) Note that capacity of EG + EH = 93 and current flow through EG + EH = 75 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | (f) | (ii) | $EH \leq 60$ only | B1ft [1] | 3.5c | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | (a) | | $x + y + z \geq 26 \Rightarrow x + y + z - s_1 + a_1 = 26$ $2x + y + z \leq 34 \Rightarrow 2x + y + z + s_2 = 34$ $2x - z = 0 \Rightarrow 2x - z \leq 10$ and $2x - z \geq 10$ $2x - z + s_3 = 10$ and $2x - z - s_4 + a_2 = 10$ $P = 3x + 2y + 5z \Rightarrow P - 3x - 2y - 5z = 0$ $Q = a_1 + a_2$ $Q + 3x + y - s_1 - s_4 = 36$ | B1 B1 B1 B1 B1 M1 A1 M1 A1 [9] | 3.1a 1.1 3.1a 1.1 3.1a 2.1 2.2a 3.3 1.1 | Implied by two correct equations Or B1 for one correct equation (if previous mark not earned) Correct form for Q and attempt to substitute their expressions for a_1 and a_2 Three rows correct cao | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | <table border="1"> <thead> <tr> <th>Q</th> <th>P</th> <th>x</th> <th>y</th> <th>z</th> <th>s_1</th> <th>s_2</th> <th>s_3</th> <th>s_4</th> <th>a_1</th> <th>a_2</th> <th>RHS</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0</td> <td>3</td> <td>1</td> <td>0</td> <td>-1</td> <td>0</td> <td>0</td> <td>-1</td> <td>0</td> <td>0</td> <td>36</td> </tr> <tr> <td>0</td> <td>1</td> <td>-3</td> <td>-2</td> <td>-5</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>0</td> <td>0</td> <td>1</td> <td>1</td> <td>1</td> <td>-1</td> <td>0</td> <td>0</td> <td>0</td> <td>1</td> <td>0</td> <td>26</td> </tr> <tr> <td>0</td> <td>0</td> <td>2</td> <td>1</td> <td>1</td> <td>0</td> <td>1</td> <td>0</td> <td>0</td> <td>0</td> <td>0</td> <td>34</td> </tr> <tr> <td>0</td> <td>0</td> <td>2</td> <td>0</td> <td>-1</td> <td>0</td> <td>0</td> <td>1</td> <td>0</td> <td>0</td> <td>0</td> <td>10</td> </tr> <tr> <td>0</td> <td>0</td> <td>2</td> <td>0</td> <td>-1</td> <td>0</td> <td>0</td> <td>0</td> <td>-1</td> <td>0</td> <td>1</td> <td>10</td> </tr> </tbody> </table> | Q | P | x | y | z | s_1 | s_2 | s_3 | s_4 | a_1 | a_2 | RHS | 1 | 0 | 3 | 1 | 0 | -1 | 0 | 0 | -1 | 0 | 0 | 36 | 0 | 1 | -3 | -2 | -5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | -1 | 0 | 0 | 0 | 1 | 0 | 26 | 0 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 34 | 0 | 0 | 2 | 0 | -1 | 0 | 0 | 1 | 0 | 0 | 0 | 10 | 0 | 0 | 2 | 0 | -1 | 0 | 0 | 0 | -1 | 0 | 1 | 10 | | | |
| Q | P | x | y | z | s_1 | s_2 | s_3 | s_4 | a_1 | a_2 | RHS | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 3 | 1 | 0 | -1 | 0 | 0 | -1 | 0 | 0 | 36 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 1 | -3 | -2 | -5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | 1 | 1 | 1 | -1 | 0 | 0 | 0 | 1 | 0 | 26 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 34 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | 2 | 0 | -1 | 0 | 0 | 1 | 0 | 0 | 0 | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | 2 | 0 | -1 | 0 | 0 | 0 | -1 | 0 | 1 | 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

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