OCR
Oxford Cambridge and RSA

GCE

Mathematics

Unit **4737**: Decision Mathematics 2

Advanced GCE

Mark Scheme for June 2017

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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.

OCR will not enter into any discussion or correspondence in connection with this mark scheme.

These are the annotations, (including abbreviations), including those used in scoris, which are used when marking

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
M1 dep*	Method 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

Here are the subject specific instructions for this question paper

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, award marks according to the spirit of the basic scheme; if you are in any doubt whatsoever (especially if several marks or candidates are involved) 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, eg 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.

Unless otherwise indicated, marks once gained cannot subsequently be lost, eg 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, exactly what is acceptable will be detailed in the mark scheme rationale. If this is not the case please consult your Team Leader.

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 Wrong or missing units in an answer should not lead to the loss of a mark unless the scheme specifically indicates otherwise. Candidates are expected to give numerical answers to an appropriate degree of accuracy, with 3 significant figures often being the norm. Small variations in the degree of accuracy to which an answer is given (e.g. 2 or 4 significant figures where 3 is expected) should not normally be penalised, while answers which are grossly over- or under-specified should normally result in the loss of a mark. The situation regarding any particular cases where the accuracy of the answer may be a marking issue should be detailed in the mark scheme rationale. If in doubt, contact your Team Leader.

g Rules for replaced work

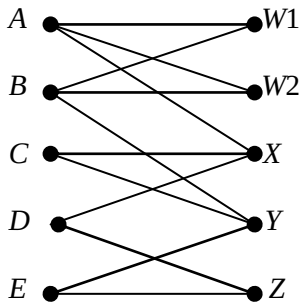
If a candidate attempts a question more than once, and indicates which attempt he/she wishes to be marked, then examiners should do as the candidate requests.

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.

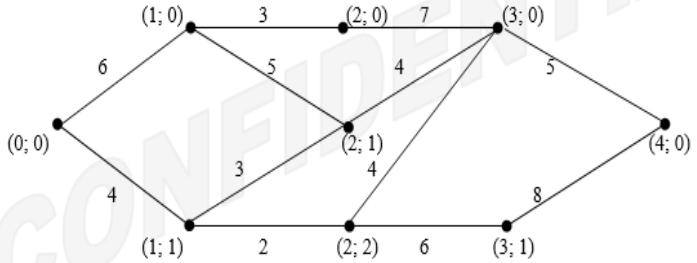
h For a *genuine* misreading (of numbers or symbols) which is such that the object and the difficulty of the question remain unaltered, mark according to the scheme but following through from the candidate's data. A penalty is then applied; 1 mark is generally appropriate, though this may differ for some units. This is achieved by withholding one A mark in the question.

Note that a miscopy of the candidate's own working is not a misread but an accuracy error.

Question			Answer/Indicative content	Mark	Guidance
1	(i)			B1 **[1]**	All correct, with five (labelled) vertices in each set. The two vertices corresponding to *W* could have any '*W*-like' labels, including both being labelled as *W*.
	(ii)		$C = X - A = W1$ *A* does *W* *B* does *Y* *C* does *X* *E* does *Z* $D = X - C = Y - B = W2$ or $D = Z - E = Y - B = W2$ (or in reverse) (or in reverse) *A* does *W* *B* does *W* *C* does *Y* *D* does *X* *E* does *Z* *A* does *W* *B* does *W* *C* does *X* *D* does *Z* *E* does *Y*	M1 A1 M1 A1 **[4]**	This alternating path, presented in any unambiguous (written) form. Must start $C - X$- (not reversed) This matching (cao) from alternating path (May see diagrams as well, but mark written matching) One of these alternating paths, presented in any unambiguous (written) form. Correct complete matching (written) from their valid alternating path Alternating paths must be seen (written) and not implied from matchings.
	(iii)		There are two ways to allocate the five workers to the tasks *W* must be done by *A* and *B* This leaves *X* to be done by *C* or *D*, *Y* by *C* or *E* and *Z* by *D* or *E*. If *X* is done by *C* then *Y* must be done by *E* and *Z* by *D* If *X* is done by *D* then *Z* must be done by *E* and *Y* by *C*	B1 M1 A1 **[3]**	2 *A* and *B* must both do *W* Explaining why there are only two ways to pair {*C*, *D*, *E*} with {*X*, *Y*, *Z*}. Needs to be more than just giving the two matchings *CX*, *DZ*, *EY* and *CY*, *DX*, *EZ*

2	(i)		B 1 4 6 row min A 2 1 –4 –4 –4 3 2 –9 –9 –9 5 4 1 –25 –25 Play-safe strategy for Tom is to choose card with value 2	 B1 B1 M1 A1 **[4]**	May have rows and columns transposed or in a different order Need to see row and column headings (2, 3, 5 and 1, 4, 6) Positive entries correct Negative entries correct Row min calculated (their -4, -9, -25) (or col min if transposed) (card) 2 (cao)
	(ii)		B 2 3 5 row min A 1 –1 –1 –1 –1 4 2 1 –16 –16 6 4 3 1 1 Play-safe strategy for Tom is to choose card with value 6	 B1 B1 B1 **[3]**	May have rows and columns transposed or in a different order Need to see row and column headings (1, 4, 6 and 2, 3, 5) Positive entries correct Negative entries correct (Card) 6 (cao)
	(iii)	(a)	Choose card with value 6	B1 **[1]**	(Card) 6
		(b)	Choose the lowest valued card	B1 **[1]**	Lowest (or any equivalent description)
	(iv)		Cards with values 3, 4 and 5	B1 **[1]**	(Cards) 3, 4, 5

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Mark</th><th>Guidance</th></tr>
<tr><td>3</td><td>(i)</td><td></td><td>Row 6 has stage = 2 and state = 2 so the arc is from (2; 2)
Row 6 has stage = 2 (stage above = 3) and action = 1 so the arc is to (2+1; 1) = (3; 1)</td><td>B1
B1

[2]</td><td>Stage = 2, state = 2
Action = 1</td></tr>
<tr><td></td><td>(ii)</td><td></td><td>
<table>
<tr><th>Stage</th><th>State</th><th>Action</th><th>Weight</th><th>Working</th><th>Maximin</th></tr>
<tr><td>3</td><td>0</td><td>0</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td></td><td>1</td><td>0</td><td>8</td><td>8</td><td>8</td></tr>
<tr><td>2</td><td>0</td><td>0</td><td>7</td><td>min(7, 5) = 5</td><td>5</td></tr>
<tr><td></td><td>1</td><td>0</td><td>4</td><td>min(4, 5) = 4</td><td>4</td></tr>
<tr><td></td><td>2</td><td>0</td><td>4</td><td>min(4, 5) = 4</td><td></td></tr>
<tr><td></td><td></td><td>1</td><td>6</td><td>min(6, 8) = 6</td><td>6</td></tr>
<tr><td>1</td><td>0</td><td>0</td><td>3</td><td>min(3, 5) = 3</td><td></td></tr>
<tr><td></td><td></td><td>1</td><td>5</td><td>min(5, 4) = 4</td><td>4</td></tr>
<tr><td></td><td>1</td><td>1</td><td>3</td><td>min(3, 4) = 3</td><td>3</td></tr>
<tr><td></td><td></td><td>2</td><td>2</td><td>min(2, 6) = 2</td><td></td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>6</td><td>min(6, 4) = 4</td><td>4</td></tr>
<tr><td></td><td></td><td>1</td><td>4</td><td>min(4, 3) = 3</td><td></td></tr>
</table>
Maximin = 4
Route: (0; 0) – (1; 0) – (2; 1) – (3; 0) – (4; 0)
For reference:
 

</td><td>B1

M1
A1

M1

A1
A1
B1

B1
B1

[9]</td><td>Values 5 and 8 in working or maximin column of first two rows

Working values for stage 2
5, 4, 4, 6 correct

Working values for stage 1

3, 4 for (1; 0)
3, 2 for (1; 1)
Identifying 4 as suboptimal maximin for (1; 0) and 3 for (1; 1)

4 (cao)
This route in this form (including ends), or in reverse (cao)

No credit for drawing the network
Shown here for reference only</td></tr>
</table>

Question	Answer/Indicative content	Mark	Guidance
4 (i)	Rows reduced 8 1 2 0 7 7 0 2 6 5 0 3 3 4 3 0 or Columns reduced 5 0 1 0 5 7 0 3 5 6 1 5 0 3 2 0 Columns reduced 5 0 2 0 4 6 0 2 3 4 0 3 0 3 3 0 Rows reduced 5 0 1 0 5 7 0 3 4 5 0 4 0 3 2 0 Augment by 2 5 0 4 0 2 4 0 0 1 2 0 1 0 3 5 0 Augment by 3 5 0 4 0 2 4 0 0 1 2 0 1 0 3 5 0 Jai = Cardiff Karen = London Mike = Glasgow Nina = Belfast	B1 M1 M1 A1 M1 A1 B1 **[7]**	Describing matrices appropriately Reducing rows to give non-negative values with a 0 in each row Reducing columns to give non-negative values with a 0 in each column Correct reduced cost matrix from their valid method Augmenting, not as several augmentations by 1, including a correct cell of each type: increased/unchanged/decreased Correct augmented matrix Correct matching identified J = C or B = N K = L C = J M = G G = M N = B L = K

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Mark</th><th>Guidance</th></tr>
<tr><td>4</td><td>(ii)</td><td></td><td>Each of Jai, Karen and Mike cost 9 for Belfast

The cheapest way to deal with Cardiff, Glasgow and London (using min values in columns) is
Nina = London cost = 1
Jai = Cardiff cost = 2
Karen = Glasgow cost = 2

Then use Mike for Belfast</td><td>B1

[1]</td><td>Min values in columns of original table</td></tr>
<tr><td></td><td>(iii)</td><td></td><td>If J = L at cost 0 then the cheapest solution swaps Jai and Nina from (ii)
This costs 16 (£16000) compared with 14 (£14000) from (ii)</td><td>B1
B1

[2]</td><td>J = L, K = G, M = B, N = C
Need to identify N = C or 5 explicitly
Showing that this costs more using original table
J = L saves 1 (compared with N = L)
J = L saves 2 (compared with J = C)</td></tr>
<tr><td></td><td>(iv)</td><td></td><td>When J = L the minimum cost is 16 (£16000)
16 – 14 = 2, so Jai at Cardiff would need to cost (at least) another 2 (£2000)
The cost would need to be (at least) 4 (£4000)
For reference:
<table>
<tr><th></th><th>Belfast</th><th>Cardiff</th><th>Glasgow</th><th>London</th></tr>
<tr><td>Jai</td><td>9</td><td>2</td><td>3</td><td>0 (1)</td></tr>
<tr><td>Karen</td><td>9</td><td>9</td><td>2</td><td>4</td></tr>
<tr><td>Mike</td><td>9</td><td>8</td><td>3</td><td>6</td></tr>
<tr><td>Nina</td><td>X (4)</td><td>5</td><td>4</td><td>1</td></tr>
</table></td><td>M1

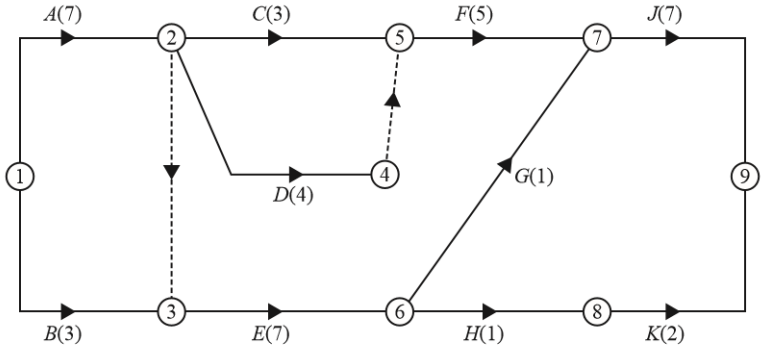
A1

[2]</td><td>Using both 16 and 14 (or 16 and 12), or using (5 + 0) and (2 + 1) or equivalent
4 (£4000)

(For reference only)
(N – B = 4 in (i) only)
(J – L = 1 in (i) and (ii))</td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answer/Indicative content</th><th>Mark</th><th>Guidance</th></tr>
<tr><td>5</td><td>(i)</td><td></td><td>Dummy from ② to ③ shows that E follows both A and B
while C and D follow A <u>only</u>

Dummy from ④ to ⑤ is needed because otherwise C and D would both connect ② to ⑤

For reference:
 
</td><td>B1
B1

B1

[3]</td><td>E follows <u>both</u> A and B
C and/or D do <u>not</u> follow B (depend on A <u>only</u>)

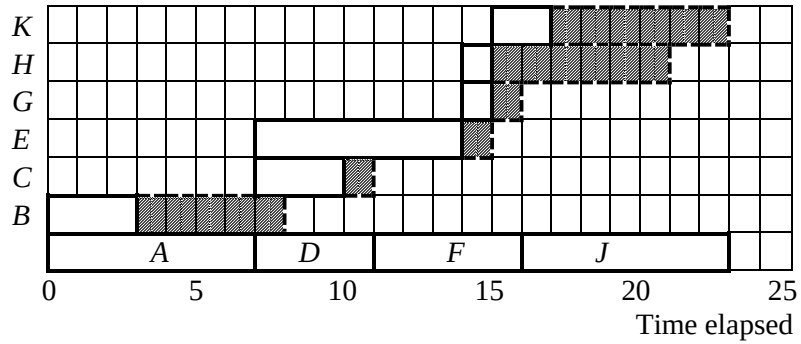
Otherwise C and D would share a start event and share a finish event.
Need a simple network so that activities can be labelled using the vertex labels (i.e. use a duration matrix)

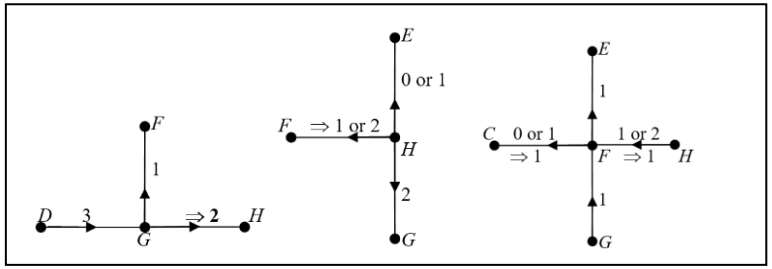
(for reference only)</td></tr>
<tr><td></td><td>(ii)</td><td></td><td><table>
<tr><td>Event</td><td>①</td><td>②</td><td>③</td><td>④</td><td>⑤</td><td>⑥</td><td>⑦</td><td>⑧</td><td>⑨</td></tr>
<tr><td>Early time</td><td>0</td><td>7</td><td>7</td><td>11</td><td>11</td><td>14</td><td>16</td><td>15</td><td>23</td></tr>
<tr><td>Late time</td><td>0</td><td>7</td><td>8</td><td>11</td><td>11</td><td>15</td><td>16</td><td>21</td><td>23</td></tr>
</table></td><td>M1

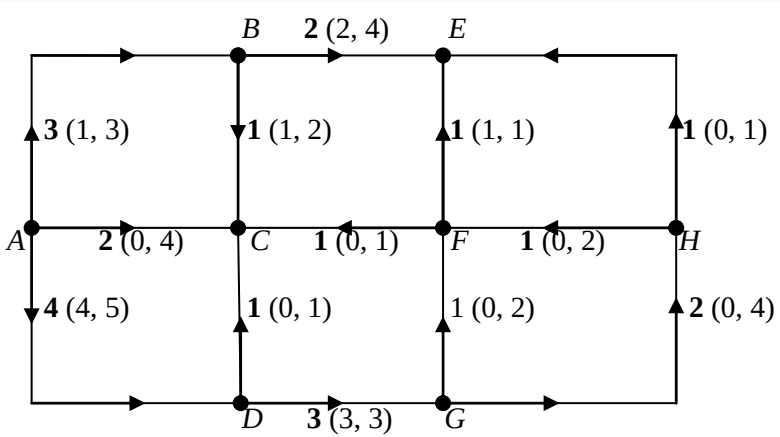
M1
A1

[3]</td><td>Forward pass (no more than 1 independent error)

Backward pass (no more than 1 independent error FT their 23)
All correct</td></tr>
<tr><td></td><td>(iii)</td><td></td><td>Minimum project completion = 23 hours
Critical activities A D F J</td><td>B1
B1
[2]</td><td>23
A D F J (in any order, with no others)</td></tr>
</table>

5	(iv)			B1 B1 B1 **[3]**	Earliest start and finish times for (labelled) non-critical activities B(0 to 3), C(7 to 10), E(7 to 14), G(14 to 15), H(14 to 15), K(15 to 16) Latest finish times for (labelled) non-critical activities B(8), C(11), E(15), G(16), H(21), K(23) Earliest start and finish times for critical activities (all on one row) (0, 7, 11, 16, 23)
	(v)		Activities *A* and *B* can be completed by two workers by time 7. Activity *E* can be done by two workers while the third does *C* and then *D*. *F*, *G*, *J* and *K* each need two workers, so with three workers they have to be done one after the other (with *H* fitting in after *E* and before *K*). This gives a minimum time of 7+7+(5+1+7+2) = 29 hours	M1 A1 **[2]**	An explanation of how three workers can do the project 29 (cao)
	(vi)		7+4+7+5+1+7+2 (*E* cannot overlap *C* and *D*) = 33 hours	M1 A1 **[2]**	 33 (cao)

Question			Answer/Indicative content	Mark	Guidance
6	(i)		Source is *A* Two sinks: *C* and *E*	B1 B1 **[2]**	*A* (and no others) Both *C* and *E* (and no others)
	(ii)		Flow = 3 $cm^3\ s^{-1}$	B1 **[1]**	(It is) 3 Allow 3 ≤ flow ≤ 3
	(iii)		At least 4 $cm^3\ s^{-1}$ in and at most 4 $cm^3\ s^{-1}$ out, so *AD* = 4 *DC* = 1	 B1 B1 **[2]**	 *AD* is at lower (min) value *DC* is at upper (max) value
	(iv)		At most 3 $cm^3\ s^{-1}$ in and at least 3 $cm^3\ s^{-1}$ out, so *AB* = 3 *BC* = 1 *BE* = 2	 B1 B1 **[2]**	 *AB* is at upper (max) value *BC* and *BE* are both at lower (min) value
	(v)		*DG* = 3 and *GF* = 1 so *GH* = 2 At most 1 flows in *HE* so at least 1 flows in *HF* *GF* = 1 = *FE* so flow in *HF* = flow in *FC* Flow in *HF* is at least 1 and flow in *FC* is at most 1, hence both equal 1 $cm^3\ s^{-1}$	B1 B1 B1 **[3]**	Flow through *G* to deduce that *GH* = 2 Flow through *H* to deduce that at least 1 flows in *HF* (not flow in *HF* = 1, until flow through *F* has been considered) Flow through *F* to deduce that flow in *FC* = 1 (as given in question) 

Question			Answer/Indicative content	Mark	Guidance
6	(vi)			B1 B1 B1 **[3]**	Flow in $AC = 2$ Flow in all other arcs correct (lower and upper capacities given here for reference but not needed in answer) These six arcs
	(vii)		Increase AC (by 2 to 4) Cut $\{A, D\}$, $\{B, C, E, F, G, H\}$	B1 M1 A1 **[3]**	AC Cut in any form Both sets correct in this form

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