OCR
Oxford Cambridge and RSA

GCE

Further Mathematics B MEI

Y433/01: Modelling with algorithms

A Level

Mark Scheme for June 2022

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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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Text Instructions

1. 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
E	Explanation mark 1
SC	Special case
^	Omission sign
MR	Misread
BP	Blank page
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 *. The * may be omitted if only previous M mark.
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.

2. Subject-specific Marking Instructions for AS Level Mathematics B (MEI)

a Annotations must be used during your marking. For a response awarded zero (or full) marks a single appropriate annotation (cross, tick, M0 or ^) is sufficient, but not required.

For responses that are not awarded either 0 or full marks, you must make it clear how you have arrived at the mark you have awarded and all responses must have enough annotation for a reviewer to decide if the mark awarded is correct without having to mark it independently.

It is vital that you annotate standardisation scripts fully to show how the marks have been awarded.

Award NR (No Response)

- if there is nothing written at all in the answer space and no attempt elsewhere in the script
- OR if there is a comment which does not in any way relate to the question (e.g. 'can't do', 'don't know')
- OR if there is a mark (e.g. a dash, a question mark, a picture) which isn't an attempt at the question.

Note: Award 0 marks only for an attempt that earns no credit (including copying out the question).

If a candidate uses the answer space for one question to answer another, for example using the space for 8(b) to answer 8(a), then give benefit of doubt unless it is ambiguous for which part it is intended.

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 always 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 method mark may usually be implied by a correct answer unless the question includes the DR statement, the command words "Determine" or "Show that", or some other indication that the method must be given explicitly.

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.
- When a value is **not given** in the paper accept any answer that agrees with the correct value to **2 s.f.** unless a different level of accuracy has been asked for in the question, or the mark scheme specifies an acceptable range.

NB for Specification A the rubric specifies 3 s.f. as standard, so this statement reads "3 s.f"

Follow through should be used so that only one mark in any question is lost for each distinct accuracy error.
Candidates using a value of 9.80, 9.81 or 10 for *g* should usually be penalised for any final accuracy marks which do not agree to the value found with 9.8 which is given in the rubric.

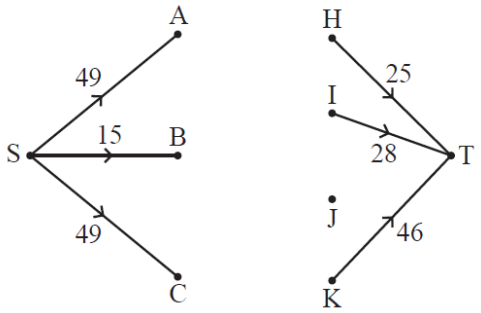
g Rules for replaced work and multiple attempts:

- If one attempt is clearly indicated as the one to mark, or only one is left uncrossed out, then mark that attempt and ignore the others.
- If more than one attempt is left not crossed out, then mark the last attempt unless it only repeats part of the first attempt or is substantially less complete.
- if a candidate crosses out all of their attempts, the assessor should attempt to mark the crossed out answer(s) as above and award marks appropriately.

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 or B mark in the question. Marks designated as cao may be awarded as long as there are no other errors. If a candidate corrects the misread in a later part, do not continue to follow through. E marks are lost unless, by chance, the given results are established by equivalent working. Note that a miscopy of the candidate's own working is not a misread but an accuracy error.

i If a calculator is used, some answers may be obtained with little or no working visible. Allow full marks for correct answers provided that there is nothing in the wording of the question specifying that analytical methods are required such as the bold "In this question you must show detailed reasoning", or the command words "Show" and "Determine. 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	AO	Guidance
1	(a)		e.g.  	B1 B1	1.1 1.1	A supersource labelled 'S' with directed arcs SA, SB and SC with weights SA = 49, SB = 15, SC = 49 (or greater) A supersink labelled 'T' with directed arcs HT, IT and KT with weights HT = 25, IT = 28, KT = 46 (or greater) If **B0 B0** then **SC B1** for all arrows correct or all weights correct, but must have all 6 correct arcs and no others from S or to T
				[2]		
	(b)		Cut $\alpha = (15+24+34+15+39=)127$	B1	1.1	cao
				[1]		
	(c)		The maximum flow out of E is 32 (ED = 8, EG = 24) therefore the maximum flow along AE is 32 < 34 (the maximum flow along AE)	B1	2.4	(At most) 32 from E
				[1]		
	(d)		e.g. Maximise AF + AE + BE + CD + CG	B1	3.3	oe e.g. maximise GH + FI + JI + FK + GK or maximise SA + SB + SC, etc.
				[1]		
	(e)		The capacity of the cut which partitions the vertices into the sets {S, A, B, C, E, G}, {D, F, H, I, J, K, T} is 15 + 10 + 8 + 25 + 29 = 87 $\therefore$ minimum cut is ≤ 87 Flow shown in Fig. 1.2 = 87 By the maximum flow-minimum cut theorem the maximum flow is equal to the minimum cut and so therefore 87 litres per minute is the maximum flow through the system	M1 A1	3.1b 2.1	Condone without S and/or T - allow listing of cut arcs (AF, CD, ED, FG, GH, JG, GK) Requires correct cut, 87 stated (as capacity and as flow) and max flow-min cut theorem (o.e.)
				[2]		

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>AO</th><th>Guidance</th></tr>
<tr><td>2</td><td>(a)</td><td></td><td>
<table>
<tr><th>A</th><th colspan="2">B</th><th>$|A-B|<0.001$?</th></tr>
<tr><td>5</td><td>4.2358236</td><td>(4.235823584…)</td><td>No</td></tr>
<tr><td>4.2358236</td><td>4.0735168</td><td>(4.073516781…)</td><td>No</td></tr>
<tr><td>4.0735168</td><td>4.0373314</td><td>(4.037331436…)</td><td>No</td></tr>
<tr><td>4.0373314</td><td>4.0291751</td><td>(4.02917514…)</td><td>No</td></tr>
<tr><td>4.0291751</td><td>4.0273321</td><td>(4.027332116…)</td><td>No</td></tr>
<tr><td>4.0273321</td><td>4.0269154</td><td>(4.026915427…)</td><td>Yes</td></tr>
</table>
Output = 4.027</td><td>M1

A1

A1</td><td>3.4

1.1

1.1</td><td>First two rows of cells completed in columns A and B, with correct values in row 1 (to at least 3 d.p.)

All values correct to at least 7 d.p.
Condone one extra row (only)

Output correct to exactly 3 d.p.
(with at least 6 rows of A and B columns and last row for both is 4.027 to 3 d.p.)</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[3]</td><td></td><td></td></tr>
<tr><td></td><td>(b)</td><td></td><td>Evaluates $f(x)=\pm\left(x^3-11x-21\right)$ at both x = 4.0265 and 4.0275

f(4.0265) = -0.011… < 0 and f(4.0275) = + 0.026… (or 0.027) > 0
change of sign
4.027 is the root of the cubic equation correct to 3 decimal places</td><td>M1

A1</td><td>1.1

2.4</td><td>Putting their output ± 0.0005 (or tighter interval) into correct f(x)
Not for finding root from calculator

Correct values (to at least 2 s.f. rot) together with explanation (change of sign) and conclusion</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[2]</td><td></td><td></td></tr>
<tr><td></td><td>(c)</td><td></td><td>Change ‘Let $B=\sqrt[3]{11A+21}$’ to ‘Let $B=\sqrt[3]{12A+23}$’</td><td>B1</td><td>3.5c</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>[1]</td><td></td><td></td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>AO</th><th>Guidance</th></tr>
<tr><td>3</td><td>(a)</td><td></td><td>Critical activities are C, E, H and K</td><td>B1</td><td>1.1</td><td>cao, no extras</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[1]</td><td></td><td></td></tr>
<tr><td>3</td><td>(b)</td><td></td><td><table><tr><th>Activity</th><th>Duration</th></tr><tr><td>A</td><td>5</td></tr><tr><td>B</td><td>7</td></tr><tr><td>C</td><td>10</td></tr><tr><td>D</td><td>2</td></tr><tr><td>E</td><td>4</td></tr><tr><td>F</td><td>5</td></tr><tr><td>G</td><td>4</td></tr><tr><td>H</td><td>3</td></tr><tr><td>I</td><td>3</td></tr><tr><td>J</td><td>5</td></tr><tr><td>K</td><td>3</td></tr></table></td><td>M1

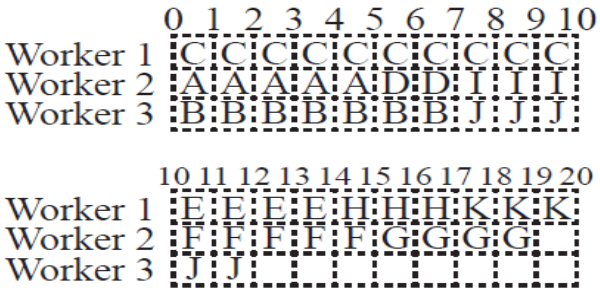
M1

A1</td><td>1.1

1.1

1.1</td><td>Any 3 rows correct

Any 6 rows correct

cao</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[3]</td><td></td><td></td></tr>
<tr><td></td><td>(c)</td><td></td><td>e.g.

</td><td>M1

A1</td><td>3.1a

1.1</td><td>3 workers used to deal with at least 10 of the activities. No activity finishes after the time 20 and structure is correct for at least 5 activities (even if durations are wrong)
D does not start until A has finished
E, F after C G, H after A, B, E
I, J after D K after F, H, I

A correct schedule</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[2]</td><td></td><td></td></tr>
</table>

Question			Answer	Marks	AO	Guidance
4	(a)		In the worst case the total number of comparisons in the first $(n-1)$ passes is $= (n-1)+(n-2)+(n-3)+\ldots+2+1 = \sum_{r=1}^{n-1} r$	M1	2.1	Explaining formula for sum. In the first pass there are at most $n-1$ comparisons (in the worst case), in the second pass there are at most $n-2$ comparisons, and so on. Ignore claims about what worst case is
			$= \frac{1}{2}(n-1)(n) = \frac{1}{2}(n^2-n) = \mathrm{O}(n^2)$	A1	2.2a	Or $\frac{1}{2}n(n+1) - n = \frac{1}{2}(n^2-n) = \mathrm{O}(n^2)$ A correct quadratic expression seen (factorised or expanded, but not written as a sum)
				[2]		
	(b)		$t \approx (2.3\times10^{-7})\left(\frac{500\,000}{100}\right)^2$ [or $(2.3 \times 10^{-11})(500\,000)^2$ oe]	M1	3.1a	Using the fact that this is an example of a worst-case quick sort and hence the order is quadratic Or implied from answer
			5.75 (seconds) or 5.8 (2 s.f.)	A1	2.2b	Allow **M1 A0** for 2.87 to 2.88 or 2.9 (2 s.f.)
				[2]		
	(c)		After two passes of the quick sort algorithm (at least) two values would be in their correct position but here only the 4 is in its correct position current 6 8 10 5 7 11 **4** final 11 10 8 7 6 5 **4**	B1	2.4	Any correct reason for why the second pass of quick sort was not completed correctly e.g. 11 needs to be further left
				[1]		

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>AO</th><th>Guidance</th></tr>
<tr><td>5</td><td>(a)</td><td></td><td>The simplex algorithm cannot be used to solve this LP problem because the origin is not in the feasible region, so there is no initial basic feasible solution</td><td>B1</td><td>3.5b</td><td>Or equivalent correct reason
e.g. cannot have negative values of z
e.g. $ax + by + cz \geq$ positive constant cannot be written in the standard form
e.g. would need 2-stage simplex/artificial variables</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[1]</td><td></td><td></td></tr>
<tr><td></td><td>(b)</td><td></td><td>$P = 2x + 3y - z \Rightarrow Q + 16 = 2(X + 4) + 3(Y + 2) - (-2 - Z)$
$3x + y - 4z \leq 70 \Rightarrow 3(X + 4) + (Y + 2) - 4(-2 - Z) \leq 70$
$5x + 4y \leq 60 \Rightarrow 5(X + 4) + 4(Y + 2) \leq 60$

(Maximise) $Q = 2X + 3Y + Z$ (with no constant added)
Subject to
$3X + Y + 4Z \leq 48$
$5X + 4Y \leq 32$
$X \geq 0, Y \geq 0, Z \geq 0$</td><td>M1

A1</td><td>1.1

2.5</td><td>Substitute given expressions into $P = 2x + 3y$, $3x + y - 4z \leq 70$ or $5x + 4y \leq 60$
Or implied from any one correct simplified expression in Q, X, Y, Z
(apart from non-negativity)

All correct (may imply non-negativity) oe
e.g. $Q - 2X - 3Y - Z = 0$
Allow use of slack variables instead of inequalities</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[2]</td><td></td><td></td></tr>
<tr><td></td><td>(c)</td><td></td><td>Initial tableau:

<table>
<tr><th>Q</th><th>X</th><th>Y</th><th>Z</th><th>s_1</th><th>s_2</th><th>RHS</th></tr>
<tr><td>1</td><td>–2</td><td>–3</td><td>–1</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td>0</td><td>3</td><td>1</td><td>4</td><td>1</td><td>0</td><td>48</td></tr>
<tr><td>0</td><td>5</td><td>4</td><td>0</td><td>0</td><td>1</td><td>32</td></tr>
</table></td><td>M1

A1</td><td>3.3

1.1</td><td>One row correct

All three rows correct (not FT and not using constraints for x, y, z given in question)</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[2]</td><td></td><td></td></tr>
</table>

<table>
<tr><th colspan="3">Question</th><th>Answer</th><th>Marks</th><th>AO</th><th>Guidance</th></tr>
<tr><td></td><td>(d)</td><td></td><td>After second iteration:

<table>
<tr><th>Q</th><th>X</th><th>Y</th><th>Z</th><th>s_1</th><th>s_2</th><th>RHS</th></tr>
<tr><td>1</td><td>$\frac{35}{16}$</td><td>0</td><td>0</td><td>$\frac{1}{4}$</td><td>$\frac{11}{16}$</td><td>34</td></tr>
<tr><td>0</td><td>$\frac{7}{16}$</td><td>0</td><td>1</td><td>$\frac{1}{4}$</td><td>$-\frac{1}{16}$</td><td>10</td></tr>
<tr><td>0</td><td>$\frac{5}{4}$</td><td>1</td><td>0</td><td>0</td><td>$\frac{1}{4}$</td><td>8</td></tr>
</table></td><td>B1

M1

A1</td><td>3.4

1.1

1.1</td><td>Pivot choice (col Z row 2) soi

Structure correct structure
(Q a basis col and 2 other basis cols, RHS ≥ 0)

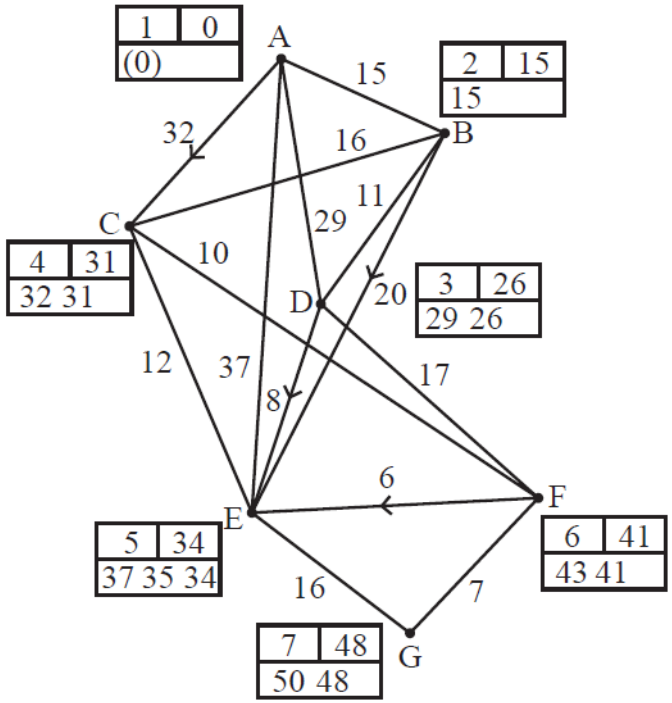
cao
using fractions or decimals (2 sf or better)</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[3]</td><td></td><td></td></tr>
<tr><td></td><td>(e)</td><td></td><td>$Q = 34 \Rightarrow P = 50$

$X = 0 \Rightarrow x = 4$
$Y = 8 \Rightarrow y = 10$
$Z = 10 \Rightarrow z = -12$</td><td>B1ft

B1ft</td><td>3.2a

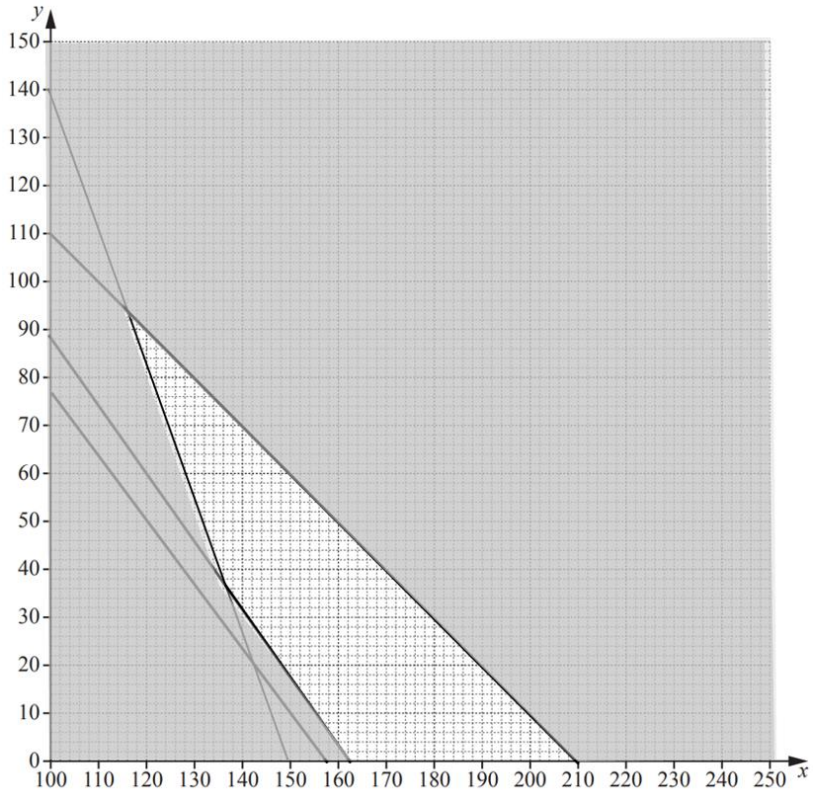
1.1</td><td>FT their second iteration,
P = their Q + 16

FT their second iteration,
x = their X + 4, y = their Y + 2, $z = -2$ – their Z</td></tr>
<tr><td></td><td></td><td></td><td></td><td>[2]</td><td></td><td></td></tr>
</table>

Question			Answer	Marks	AO	Guidance
6	(a)					
			Shortest path from A to G: ABCFG	M1	1.2	Working values 29, 26 at D
				A1	1.1a	All working values correct, no extras
				A1	1.1a	All (permanent) labels correct in top box Accept top boxes swapped throughout
				A1	1.1	Order of labelling correct for their labels
				B1	2.2a	cao
				[5]		

Question			Answer	Marks	AO	Guidance
	(b)	**(i)**	AB + AE + AC + AD = 1, A is the start vertex and so this constraint ensures that the longest path contains only one of the four arcs incident to A	**B1**	**3.3**	Only one arc from A is used in the longest path (path does not return to A)
				[1]		
		(ii)	CF + DF – FC – FD – FE – FG = 0, this constraint ensures that the number of arcs that are in the longest path that go into node F will always equals the number of arcs (in the longest path) that come out of F	**B1**	**3.3**	Number of arcs used into F = number of arcs used from F (if the path enters F then it leaves F and if the path does not enter F then it does not leave F)
				[1]		
		(iii)	$CE + EC \leq 1$, this constraint ensures that <u>if</u> the longest path uses arc CE/EC it can only use this arc once (in either direction)	**B1**	**3.3**	Cannot use both CE and EC Uses CE or EC or neither but not both
				[1]		
	(c)	**(i)**	131	**B1**	**1.1**	cao
				[1]		
		(ii)	ACBECFDEG ACFDECBEG	**B1** **B1**	**1.1** **1.1**	cao cao (for both marks must have no other routes)
				[2]		

Question			Answer	Marks	AO	Guidance
7	(a)		$P_{\max} = 5x + 8y + 12z \Rightarrow P_{\max} = 5x + 8y + 12(210 - x - y)$	M1	3.1b	Substituting the condition $x + y + z = 210$ into an expression for P to obtain an expression in x and y only
			$P_{\max} = -(7x + 4y) + 2520$ so maximising $-(7x + 4y)$ is equivalent to minimising $7x + 4y$	A1	2.4	
				[2]		
	(b)		$\frac{x}{250} + \frac{y}{175} + \frac{z}{150} \leq 1$ material constraint	B1	3.1b	oe e.g. $21x + 30y + 35z \leq 5250$
			$40x + 70y + 140z \leq 13200$ time constraint	B1	3.3	oe e.g. $4x + 7y + 14z \leq 1320$
			$3z \leq x$ demand constraint	B1	3.3	oe
			Substituting $z = 210 - x - y$ into any constraint to eliminate z	M1	3.4	
			$14x + 5y \geq 2100$ $10x + 7y \geq 1620$	A1	1.1	Any one correct non-trivial constraint in x and y only (with integer coefficients)
			$4x + 3y \geq 630$ $x + y \leq 210$ $(x, y \geq 0)$	A1	1.1	All non-trivial constraints in x and y correct
				[6]		

Question	Answer	Marks	AO	Guidance
(c)		M1	1.1	Any one non-trivial constraint line correct
		M1	1.1	Any two lines non-trivial constraint lines correct
		A1	1.1	All lines correct and feasible region identified correctly (by shading or by labelling e.g. FR) Ignore profit lines if shown Lines cut horizontal and vertical edges at: $14x + 5y = 2100 \rightarrow (150, 0), (100, 140)$ $10x + 7y = 1620 \rightarrow (162, 0), (100, 88.5)$ $4x + 3y = 630 \rightarrow (157.5, 0), (100, 76.7)$ $x + y = 210 \rightarrow (210, 0), (100, 110)$
	Optimal point is $(137.5, 35)$	B1	1.1	Coordinates of optimal point correct
	(135, 42): 1113; (136, 40): 1112; (137, 37): 1107; (138, 35): 1106; (139, 33): 1105; (140, 32): 1108; (141, 30): 1107	M1	2.3	Testing $P = 7x + 4y$ at integer-valued (feasible) points near their optimal point, soi
	139 small cars, 33 medium cars and 38 large cars	A1 [6]	2.2a	Correct and in context
(d)	Income = (£) 1415	B1 ft	3.4	FT their non-negative integer valued solution 5(their 139) + 8(their 33) + 12(their 38) where their 38 = 210 – their 139 – their 33
		[1]		

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