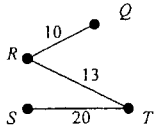
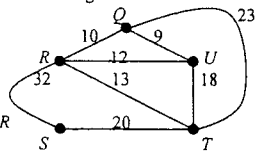
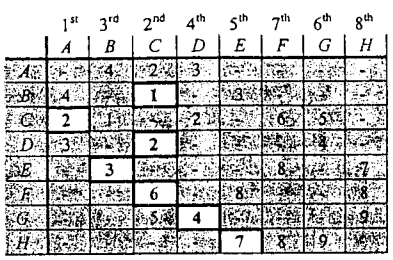
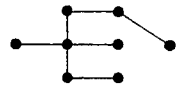
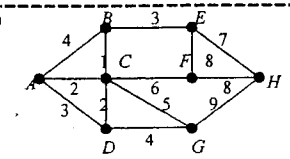
1		Original list 6 5 9 4 5 2		Decreasing order can score method marks only
		After 1st pass **5 6** 9 4 5 2	M1	For 1st pass correct with shuttle sort
		After 2nd pass **5 6 9** 4 5 2	M1	For 2nd pass correct with shuttle sort or follow through from previous list
		After 3rd pass **4 5 6 9** 5 2	M1	For 3rd pass correct with shuttle sort or follow through from previous list
		After 4th pass **4 5 5 6 9** 2	M1	For 4th pass correct with shuttle sort or follow through from previous list
		After 5th pass 2 4 5 5 6 9	A1	For final list from correct shuttle sort, with results at end of each pass clearly shown
		May be shown vertically	5	
2	(i)	Number of arcs × 2 = sum of orders of vertices ⇒ (3+3+4+4+4+4) ÷ 2 = 11 arcs	M1 A1	For a general method For 11 calculated Drawing a specific case to get 11 scores B1 only
	(ii)	Semi-Eulerian, it has exactly two odd vertices	B1	For semi-Eulerian with avalid reason Accept 'two odd nodes'or 'two nodes of order 3' as minimal reasons
	(iii)	Complete graph on five vertices has only 10 arcs, so 11 arcs means that all six vertices are connected. Or, a vertex of order 4 must join to four others so five vertices are connected. The sixth vertex has order at least three and cannot connect to itself so it must join to the other five. Or any equivalent reasoning.	B2 5	For a good explanation of the general case by considering orders of vertices A weak explanation may score B1 A diagram of a specific case is not sufficient
3	(i)	Minimum spanning tree with U removed  $QR + RT + TS = 43$ miles	M1	For 43 or arcs QR, RT, TS or a convincing attempt to find minimum spanning tree for $\{Q, R, S, T\}$
		Join U back in using two shortest arcs 43 + 9 + 12 = 64 miles	M1 A1	For their 43 + 9 + 12 cao (miles may be implied)
	(ii)	Trying to apply nearest neighbour method  Start from R to give $RQUTSR$ = 89 miles	M1 M1 A1 A1 7	For a correct start to an application of nearest neighbour with any start vertex, ie at least: $QURTS$, $STRQU$, $TRQU$ or $UQRTS$ For R as start vertex (may be implied from cycle) For $RQUTSR$ For 89 (miles may be implied) from valid method

4	(i)	 		Answer should be on insert
			M1	For starting by choosing row C in column A
			M1	For choosing more than one entry from column C
			A1	For a correct order (A), C, B, D, E, G, F, H
			B1	For correct entries chosen or a correct tree drawn 
		Quickest time is at least 25 hours	B1	For 25 Accept 'more than 25'
	(ii)	 	M1 A1	For a correct graph drawn For correct weights shown
	(iii)	If AC is used then either B or D is excluded. Or must pass through C in getting between B and D, so AC is impossible.	B1	Follow through graph, if possible, provided same conclusion is valid For explaining what happens if AC is used or why AC cannot be included.
	(iv)	If EF is not used then passing through either E or F will take the team to H, the team will not be able to visit both E and F.	B1	Follow through graph, if possible, provided same conclusion is valid For stating the effect of not using arc EF or for considering all possible routes into H
	(v)	$A\ B\ E\ F\ C\ D\ G\ H$ $A\ D\ G\ C\ B\ E\ F\ H$ The second route is quicker (32 hours compared with 36 hours)	M1 M1 A1 12	Follow through graph, if possible For this route For this route For identifying $A\ D\ G\ C\ B\ E\ F\ H$ as the quicker or for calculating 32

5	(i)	$x \geq 0, y \geq 0$	B1	For both trivial constraints; allow >
		$y \leq 2x + 1$	B1	For this inequality, or equivalent; allow <
		$4x + 3y \leq 12$	B1	For this inequality, or equivalent; allow <
	(ii)	(0, 0), (3, 0), (0, 1)	B2	For these three vertices, any two correct ⇒ B1
		(0.9, 2.8)	B1	For this vertex exact, in decimals or fractions
		$(0, 0) \rightarrow P = 0$; $(0, 1) \rightarrow P = 3$;	M1	For calculating $P = 5x + 3y$ for at least one of their vertices or clear evidence of using an appropriate line of constant profit
		$(0.9, 2.8) \rightarrow P = 12.9$; $(3, 0) \rightarrow P = 15$		
		$x = 3$ and $y = 0$	A1	For the correct values of x and y clearly identified
		$P = 15$	A1	For 15 clearly identified as the optimum value
	(iii)	Either consider the gradient of the profit line ($-\frac{1}{3}a$) and the gradients of the boundary lines (2 and $-1\frac{1}{3}$)	M1 M1	One method mark for each appropriate gradient calculated correctly or for each appropriate value
		or calculate Q at vertices ⇒ 3, $0.9a+8.4$, $3a$	M1	of Q calculated correctly
		Hence require $a \leq -6$	A1	For the correct set of values identified [$a = -6$ or any valid proper subset of the correct answer with no method shown ⇒ B1 only]
			13	
6	(i)	$5x + 3y - 5z + s = 15$		
		$2x + 6y + 8z + t = 24$	B1	For both equations correctly stated
	(ii)		B1	For ± (-2 5 1) in objective row Follow through from part (i)

P	x	y	z	s	t	-
1	-2	5	1	0	0	0
0	5	3	-5	1	0	15
0	2	6	8	0	1	24

	B1	For 5 3 -5 1 0 15 and 2 6 8 0 1 24 or equivalent in constraint rows
Pivot on 5 in x column	B1	For correct pivot choice for their tableau

P	x	y	z	s	t	-
1	0	6.2	-1	0.4	0	6
0	1	0.6	-1	0.2	0	3
0	0	4.8	10	-0.4	1	18

	M1	For a correct method for their table and their pivot choice
	M1	For increasing P
	A1	For correct tableau or equivalent, cao
(iii)		ft their tableau provided not yet optimal
Pivot on 10 in z column	M1	For correct pivot choice

P	x	y	z	s	t	-
1	0	6.68	0	0.36	0.1	7.8
0	1	1.08	0	0.16	0.1	4.8
0	0	0.48	1	-0.04	0.1	1.8

	A1	For correct tableau or equivalent, cao
$x = 4.8$, $y = 0$, $z = 1.8$	B1	For all three correct values for their final tableau
$P = 7.8$	B1	For correct value for their final tableau
(iv) We must now pivot on the 2 in the x column, this gives		

P	x	y	z	s	t	-
1	0	11	9	0	1	24
0	0	-12	-25	1	-2.5	k-60
0	1	3	4	0	0.5	12

	M1	For showing what happens to tableau, only need to show enough to be able to deduce answer (eg top row: 0 11 9 0 1 or y column)
Hence $y = 0$ Accept 'no change to y'	A1	For correctly deducing $y = 0$ in general case. Only using a specific value of k (eg $k = 60$) with no general argument ⇒ M1, A0 Do not imply method mark from statement '$y = 0$' with no method seen.
	13	

7				Answer should be on insert
(a)	(i)	A  B 	M1	For correct temporary labels at D and E (condone extras here)
		C  D 	A1	For all temporary labels correct **(with no extras)**
		E  F 	M1	For value 38 at J
			A1	For all permanent labels correct
		G H 	B1	For the correct order of assigning permanent labels: $A, B, C, D, G, E, F, H, J$
		J 		
		Shortest route: $A - B - G - E$ Length = 900	B1	For correct route and length. Accept route reversed and accept length = 9
		Shortest route: $A - C - D - F - H - J$ Length = 3800	B1	For correct route and length. Accept route reversed and accept length = 38
	(ii)			Follow through from (i), if possible
		Length: 4700 metres	B1	For 47 or 4700
			M1	For $E - G - B - A$, or reversed, as part of a longer route
		$E - G - B - A - C - D - F - H - J$	M1	For $A - C - D - F - H - J$, or reversed, as part of a longer route
			A1	For whole route correct
	(iii)	Explanation:		May be implied
		$G - B - A - C - D - F - H$	M1	For identifying that route will not visit every
		E and J will be left out (either is sufficient)	A1	vertex.
(b)		Odd nodes are A, C, D, E, F, G		
		Need to pair C, D, F, G in the shortest way	M1	For trying to pair C, D, F, G (and no others)
		$CD = 3$ and $FG = 7 \Rightarrow 10$ ($CF = 10$, $DG = 11$ and $CG = 8$, $DF = 7$)	A1	For CD, FG or 10 (or 1000)
		Sum of all weights = 147	M1	For 147 (or 14700) or a good attempt seen or implied
		Length = 15700 metres	A1	For 15700 metres (or 15700 m or 157 hundred metres or 15.7 km). But 157 ⇒ M1, A0
			17	