**DECISION ANALYTICS**

Assignment 2: Linear Programming

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* Task1:

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| A.Load the input data from the file Assignment\_DA\_2\_Task\_1\_data.xlsx [18-59] |
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| B. Create decision variable [84-127] |
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| C: factories produce more than they ship to the customers  D: customer demand is met  F: factories order enough material to be able to manufacture all items [167-223] |
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| E. suppliers have all ordered items in stock [129-145] |
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| G> ensure that the manufacturing capacities are not exceeded [147-165] |
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| H. Objective [227-260] |
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| I. Solve the linear program and determine the optimal overall cost |
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| ==================================================  I.Optimal cost:49315.0  ================================================== |
| J. for each factory how much material has to be ordered from each individual supplier [270-286] |
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| ==================================================  J.For each factory, Material ordered from each supplier  ==================================================  **Factory A**  *Supplier B->Material B-> 4.0*  *Supplier B->Material A-> 19.0*  *Supplier D->Material D-> 50.0*  *Supplier D->Material C-> 14.0*  *Supplier A->Material B-> 20.0*  *Supplier A->Material A-> 20.0*  **Factory B**  *Supplier B->Material B-> 34.0*  *Supplier B->Material A-> 6.0*  *Supplier D->Material C-> 6.0*  *Supplier C->Material D-> 5.0*  *Supplier C->Material C-> 32.0*  *Supplier E->Material A-> 4.0*  **Factory C**  *Supplier B->Material B-> 6.0*  *Supplier C->Material D-> 35.0*  *Supplier C->Material B-> 10.0*  *Supplier C->Material C-> 20.0*  *Supplier E->Material D-> 40.0*  *Supplier E->Material A-> 25.0* |
| K. for each factory what the supplier bill comprising material cost and delivery will be for each supplier [287-309] |
|  |
| K.Supplier bill for each factory:  ==================================================  **Factory A**  *Supplier B->2155.0*  *Supplier D->6440.0*  *Supplier A->2800.0*  *Supplier C->0.0*  *Supplier E->0.0*  **Factory B**  *Supplier B->3500.0*  *Supplier D->1380.0*  *Supplier A->0.0*  *Supplier C->8550.0*  *Supplier E->260.0*  **Factory C**  *Supplier B->1590.0*  *Supplier D->0.0*  *Supplier A->0.0*  *Supplier C->12450.0*  *Supplier E->7325.0* |
| L. for each factory how many units of each product are being manufactured  determine the total manufacturing cost for each individual factory [311-341] |
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| L.Unit of product manufactured and production cost for each factory:  ==================================================  **Factory A**  *Product C->0.0*  *Product D->3.0*  *Product B->1.0*  *Product A->6.0*  *Production Cost:1010.0*  **Factory B**  *Product C->4.0*  *Product D->0.0*  *Product B->1.0*  *Product A->2.0*  *Production Cost:430.0*  **Factory C**  *Product C->0.0*  *Product D->5.0*  *Product B->0.0*  *Product A->2.0*  *Production Cost:425.0* |
| M. for each customer how many units of each product are being shipped from each factory  determine the total shipping cost per customer [343-367] |
|  |
| M.Unit of product shipped from each Factory for customer and total shipping cost:  ==================================================  **Customer C**  *->Factory A*  *-->Product B->1.0*  *->Factory B*  *-->Product B->1.0*  *->Factory C*  *-->Product D->3.0*  *Total Shipping Cost: 170.0*  **Customer A**  *->Factory A*  *-->Product A->5.0*  *->Factory B*  *->Factory C*  *-->Product D->1.0*  *-->Product A->2.0*  *Total Shipping Cost: 70.0*  **Customer D**  *->Factory A*  *-->Product D->3.0*  *->Factory B*  *-->Product C->4.0*  *->Factory C*  *-->Product D->1.0*  *Total Shipping Cost: 175.0*  **Customer B**  *->Factory A*  *-->Product A->1.0*  *->Factory B*  *-->Product A->2.0*  *->Factory C*  *Total Shipping Cost: 90.0* |
| N. for each customer the fraction of each material each factory has to order for manufacturing products delivered to that particular customer [370-493] |
|  |
| N.Fraction of raw material factory has ordered for each customer  ==================================================  **Factory A**  **Customer C**  *Material D->0.1*  *Material B->0.0*  *Material C->0.14*  *Material A->0.0*  **Customer A**  *Material D->0.0*  *Material B->0.62*  *Material C->0.0*  *Material A->0.64*  **Customer D**  *Material D->0.9*  *Material B->0.25*  *Material C->0.86*  *Material A->0.23*  **Customer B**  *Material D->0.0*  *Material B->0.13*  *Material C->0.0*  *Material A->0.13*  **Factory B**  **Customer C**  *Material D->1.0*  *Material B->0.0*  *Material C->0.05*  *Material A->0.0*  **Customer A**  *Material D->0.0*  *Material B->0.0*  *Material C->0.0*  *Material A->0.0*  **Customer D**  *Material D->0.0*  *Material B->0.82*  *Material C->0.95*  *Material A->0.0*  **Customer B**  *Material D->0.0*  *Material B->0.18*  *Material C->0.0*  *Material A->1.0*  *Factory C*  **Customer C**  *Material D->0.6*  *Material B->0.37*  *Material C->0.6*  *Material A->0.36*  **Customer A**  *Material D->0.2*  *Material B->0.5*  *Material C->0.2*  *Material A->0.52*  **Customer D**  *Material D->0.2*  *Material B->0.12*  *Material C->0.2*  *Material A->0.12*  **Customer B**  *Material D->0.0*  *Material B->0.0*  *Material C->0.0*  *Material A->0.0* |
| overall unit cost of each product per customer |
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|  |
| N.Overall Unit cost for each product per customer:  ==================================================  **Customer C:**  *Product D -> 4003.75*  *Product B -> 1026.84*  **Customer A:**  *Product D -> 3913.75*  *Product A -> 910.98*  **Customer D:**  *Product C -> 2921.58*  *Product D -> 2759.01*  **Customer B:**  *Product A -> 745.71* |

* Task2:

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| A. create a decision variable to decide if this leg should be included into the route [520-532] |
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| B. delivery driver arrives in each of the towns that need to be visited [534-550] |
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| C. constraints that ensure that the driver departs each of the towns that need to be visited[551-568] |
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| D. constraints that ensure that there are no disconnected self-contained circles in the route[570-607] |
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| E. objective function to minimise the overall distance travelled [609-620] |
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| F. overall distance that needs to be travelled to visit all towns [622-650] |
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| F. **Distance needs to travelled :1065.0**  Output the optimal route starting and ending in Cork:  *Cork->Limerick*  *Limerick->Galway*  *Galway->Athlone*  *Athlone->Belfast*  *Belfast->Dublin*  *Dublin->Wicklow*  *Wicklow->Wexford*  *Wexford->Rosslare*  *Rosslare->Waterford*  *Waterford->Cork* |

* Task3:

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| A. Load the input data from the file Assignment\_DA\_2\_Task\_3\_data.xlsx [660-678] |
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| B. For each pair of train stations determine the amount of time required to travel between the two[680-842] |
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| a.each two stations connected by a train line create a decision variable to decide if this leg should be included into the route |
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| b. |
|  |
| c. objective function to minimise the overall travel time |
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| d. solve the linear program and calculate travel time  Optimal travel route  Train lines operating on each legs |
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| *A-->B:Travel Time:3.0 Travel Route:['A', 'B']: Train Line:['L4']*  *A-->C:Travel Time:10.0 Travel Route:['A', 'B', 'C']: Train Line:['L4', 'L4']*  *A-->D:Travel Time:15.0 Travel Route:['A', 'B', 'C', 'D']: Train Line:['L4', 'L4', 'L3']*  *A-->E:Travel Time:19.0 Travel Route:['A', 'B', 'C', 'D', 'E']: Train Line:['L4', 'L4', 'L3', 'L3']*  *A-->F:Travel Time:12.0 Travel Route:['A', 'B', 'C', 'F']: Train Line:['L4', 'L4', 'L4']*  *A-->G:Travel Time:15.0 Travel Route:['A', 'B', 'C', 'F', 'G']: Train Line:['L4', 'L4', 'L4', 'L4']*  *A-->H:Travel Time:18.0 Travel Route:['A', 'B', 'C', 'F', 'G', 'H']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4']*  *A-->I:Travel Time:21.0 Travel Route:['A', 'B', 'C', 'F', 'G', 'H', 'I']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4', 'L4']*  *A-->J:Travel Time:23.0 Travel Route:['A', 'B', 'C', 'F', 'K', 'J']: Train Line:['L4', 'L4', 'L4', 'L2', 'L1']*  *A-->K:Travel Time:17.0 Travel Route:['A', 'B', 'C', 'F', 'K']: Train Line:['L4', 'L4', 'L4', 'L2']*  *A-->L:Travel Time:30.0 Travel Route:['A', 'B', 'C', 'F', 'K', 'J', 'L']: Train Line:['L4', 'L4', 'L4', 'L2', 'L1', 'L4']*  *A-->M:Travel Time:28.0 Travel Route:['A', 'B', 'C', 'F', 'N', 'M']: Train Line:['L4', 'L4', 'L4', 'L2', 'L1']*  *A-->N:Travel Time:21.0 Travel Route:['A', 'B', 'C', 'F', 'N']: Train Line:['L4', 'L4', 'L4', 'L2']*  *A-->O:Travel Time:26.0 Travel Route:['A', 'B', 'C', 'F', 'N', 'O']: Train Line:['L4', 'L4', 'L4', 'L2', 'L2']*  *A-->P:Travel Time:34.0 Travel Route:['A', 'B', 'C', 'F', 'G', 'H', 'I', 'P']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4', 'L4', 'L3']*  *A-->Q:Travel Time:20.0 Travel Route:['A', 'B', 'C', 'F', 'G', 'Q']: Train Line:['L4', 'L4', 'L4', 'L4', 'L1']*  *B-->A:Travel Time:3.0 Travel Route:['B', 'A']: Train Line:['L4']*  *B-->C:Travel Time:7.0 Travel Route:['B', 'C']: Train Line:['L4']*  *B-->D:Travel Time:12.0 Travel Route:['B', 'C', 'D']: Train Line:['L4', 'L3']*  *B-->E:Travel Time:16.0 Travel Route:['B', 'C', 'D', 'E']: Train Line:['L4', 'L3', 'L3']*  *B-->F:Travel Time:9.0 Travel Route:['B', 'C', 'F']: Train Line:['L4', 'L4']*  *B-->G:Travel Time:12.0 Travel Route:['B', 'C', 'F', 'G']: Train Line:['L4', 'L4', 'L4']*  *B-->H:Travel Time:15.0 Travel Route:['B', 'C', 'F', 'G', 'H']: Train Line:['L4', 'L4', 'L4', 'L4']*  *B-->I:Travel Time:18.0 Travel Route:['B', 'C', 'F', 'G', 'H', 'I']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4']*  *B-->J:Travel Time:20.0 Travel Route:['B', 'C', 'F', 'K', 'J']: Train Line:['L4', 'L4', 'L2', 'L1']*  *B-->K:Travel Time:14.0 Travel Route:['B', 'C', 'F', 'K']: Train Line:['L4', 'L4', 'L2']*  *B-->L:Travel Time:27.0 Travel Route:['B', 'C', 'F', 'K', 'J', 'L']: Train Line:['L4', 'L4', 'L2', 'L1', 'L4']*  *B-->M:Travel Time:25.0 Travel Route:['B', 'C', 'F', 'N', 'M']: Train Line:['L4', 'L4', 'L2', 'L1']*  *B-->N:Travel Time:18.0 Travel Route:['B', 'C', 'F', 'N']: Train Line:['L4', 'L4', 'L2']*  *B-->O:Travel Time:23.0 Travel Route:['B', 'C', 'F', 'N', 'O']: Train Line:['L4', 'L4', 'L2', 'L2']*  *B-->P:Travel Time:31.0 Travel Route:['B', 'C', 'F', 'G', 'H', 'I', 'P']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4', 'L3']*  *B-->Q:Travel Time:17.0 Travel Route:['B', 'C', 'F', 'G', 'Q']: Train Line:['L4', 'L4', 'L4', 'L1']*  *C-->A:Travel Time:10.0 Travel Route:['C', 'B', 'A']: Train Line:['L4', 'L4']*  *C-->B:Travel Time:7.0 Travel Route:['C', 'B']: Train Line:['L4']*  *C-->D:Travel Time:5.0 Travel Route:['C', 'D']: Train Line:['L3']*  *C-->E:Travel Time:9.0 Travel Route:['C', 'D', 'E']: Train Line:['L3', 'L3']*  *C-->F:Travel Time:2.0 Travel Route:['C', 'F']: Train Line:['L4']*  *C-->G:Travel Time:5.0 Travel Route:['C', 'F', 'G']: Train Line:['L4', 'L4']*  *C-->H:Travel Time:8.0 Travel Route:['C', 'F', 'G', 'H']: Train Line:['L4', 'L4', 'L4']*  *C-->I:Travel Time:11.0 Travel Route:['C', 'F', 'G', 'H', 'I']: Train Line:['L4', 'L4', 'L4', 'L4']*  *C-->J:Travel Time:13.0 Travel Route:['C', 'F', 'K', 'J']: Train Line:['L4', 'L2', 'L1']*  *C-->K:Travel Time:7.0 Travel Route:['C', 'F', 'K']: Train Line:['L4', 'L2']*  *C-->L:Travel Time:20.0 Travel Route:['C', 'F', 'K', 'J', 'L']: Train Line:['L4', 'L2', 'L1', 'L4']*  *C-->M:Travel Time:18.0 Travel Route:['C', 'F', 'N', 'M']: Train Line:['L4', 'L2', 'L1']*  *C-->N:Travel Time:11.0 Travel Route:['C', 'F', 'N']: Train Line:['L4', 'L2']*  *C-->O:Travel Time:16.0 Travel Route:['C', 'F', 'N', 'O']: Train Line:['L4', 'L2', 'L2']*  *C-->P:Travel Time:24.0 Travel Route:['C', 'F', 'G', 'H', 'I', 'P']: Train Line:['L4', 'L4', 'L4', 'L4', 'L3']*  *C-->Q:Travel Time:10.0 Travel Route:['C', 'F', 'G', 'Q']: Train Line:['L4', 'L4', 'L1']*  *D-->A:Travel Time:15.0 Travel Route:['D', 'C', 'B', 'A']: Train Line:['L3', 'L4', 'L4']*  *D-->B:Travel Time:12.0 Travel Route:['D', 'C', 'B']: Train Line:['L3', 'L4']*  *D-->C:Travel Time:5.0 Travel Route:['D', 'C']: Train Line:['L3']*  *D-->E:Travel Time:4.0 Travel Route:['D', 'E']: Train Line:['L3']*  *D-->F:Travel Time:7.0 Travel Route:['D', 'C', 'F']: Train Line:['L3', 'L4']*  *D-->G:Travel Time:10.0 Travel Route:['D', 'C', 'F', 'G']: Train Line:['L3', 'L4', 'L4']*  *D-->H:Travel Time:13.0 Travel Route:['D', 'C', 'F', 'G', 'H']: Train Line:['L3', 'L4', 'L4', 'L4']*  *D-->I:Travel Time:16.0 Travel Route:['D', 'C', 'F', 'G', 'H', 'I']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4']*  *D-->J:Travel Time:18.0 Travel Route:['D', 'C', 'F', 'K', 'J']: Train Line:['L3', 'L4', 'L2', 'L1']*  *D-->K:Travel Time:12.0 Travel Route:['D', 'C', 'F', 'K']: Train Line:['L3', 'L4', 'L2']*  *D-->L:Travel Time:25.0 Travel Route:['D', 'C', 'F', 'K', 'J', 'L']: Train Line:['L3', 'L4', 'L2', 'L1', 'L4']*  *D-->M:Travel Time:23.0 Travel Route:['D', 'C', 'F', 'N', 'M']: Train Line:['L3', 'L4', 'L2', 'L1']*  *D-->N:Travel Time:16.0 Travel Route:['D', 'C', 'F', 'N']: Train Line:['L3', 'L4', 'L2']*  *D-->O:Travel Time:21.0 Travel Route:['D', 'C', 'F', 'N', 'O']: Train Line:['L3', 'L4', 'L2', 'L2']*  *D-->P:Travel Time:29.0 Travel Route:['D', 'C', 'F', 'G', 'H', 'I', 'P']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4', 'L3']*  *D-->Q:Travel Time:15.0 Travel Route:['D', 'C', 'F', 'G', 'Q']: Train Line:['L3', 'L4', 'L4', 'L1']*  *E-->A:Travel Time:19.0 Travel Route:['E', 'D', 'C', 'B', 'A']: Train Line:['L3', 'L3', 'L4', 'L4']*  *E-->B:Travel Time:16.0 Travel Route:['E', 'D', 'C', 'B']: Train Line:['L3', 'L3', 'L4']*  *E-->C:Travel Time:9.0 Travel Route:['E', 'D', 'C']: Train Line:['L3', 'L3']*  *E-->D:Travel Time:4.0 Travel Route:['E', 'D']: Train Line:['L3']*  *E-->F:Travel Time:11.0 Travel Route:['E', 'D', 'C', 'F']: Train Line:['L3', 'L3', 'L4']*  *E-->G:Travel Time:14.0 Travel Route:['E', 'D', 'C', 'F', 'G']: Train Line:['L3', 'L3', 'L4', 'L4']*  *E-->H:Travel Time:17.0 Travel Route:['E', 'D', 'C', 'F', 'G', 'H']: Train Line:['L3', 'L3', 'L4', 'L4', 'L4']*  *E-->I:Travel Time:20.0 Travel Route:['E', 'D', 'C', 'F', 'G', 'H', 'I']: Train Line:['L3', 'L3', 'L4', 'L4', 'L4', 'L4']*  *E-->J:Travel Time:22.0 Travel Route:['E', 'D', 'C', 'F', 'K', 'J']: Train Line:['L3', 'L3', 'L4', 'L2', 'L1']*  *E-->K:Travel Time:16.0 Travel Route:['E', 'D', 'C', 'F', 'K']: Train Line:['L3', 'L3', 'L4', 'L2']*  *E-->L:Travel Time:29.0 Travel Route:['E', 'D', 'C', 'F', 'K', 'J', 'L']: Train Line:['L3', 'L3', 'L4', 'L2', 'L1', 'L4']*  *E-->M:Travel Time:27.0 Travel Route:['E', 'D', 'C', 'F', 'N', 'M']: Train Line:['L3', 'L3', 'L4', 'L2', 'L1']*  *E-->N:Travel Time:20.0 Travel Route:['E', 'D', 'C', 'F', 'N']: Train Line:['L3', 'L3', 'L4', 'L2']*  *E-->O:Travel Time:25.0 Travel Route:['E', 'D', 'C', 'F', 'N', 'O']: Train Line:['L3', 'L3', 'L4', 'L2', 'L2']*  *E-->P:Travel Time:33.0 Travel Route:['E', 'D', 'C', 'F', 'G', 'H', 'I', 'P']: Train Line:['L3', 'L3', 'L4', 'L4', 'L4', 'L4', 'L3']*  *E-->Q:Travel Time:19.0 Travel Route:['E', 'D', 'C', 'F', 'G', 'Q']: Train Line:['L3', 'L3', 'L4', 'L4', 'L1']*  *F-->A:Travel Time:12.0 Travel Route:['F', 'C', 'B', 'A']: Train Line:['L4', 'L4', 'L4']*  *F-->B:Travel Time:9.0 Travel Route:['F', 'C', 'B']: Train Line:['L4', 'L4']*  *F-->C:Travel Time:2.0 Travel Route:['F', 'C']: Train Line:['L4']*  *F-->D:Travel Time:7.0 Travel Route:['F', 'C', 'D']: Train Line:['L4', 'L3']*  *F-->E:Travel Time:11.0 Travel Route:['F', 'C', 'D', 'E']: Train Line:['L4', 'L3', 'L3']*  *F-->G:Travel Time:3.0 Travel Route:['F', 'G']: Train Line:['L4']*  *F-->H:Travel Time:6.0 Travel Route:['F', 'G', 'H']: Train Line:['L4', 'L4']*  *F-->I:Travel Time:9.0 Travel Route:['F', 'G', 'H', 'I']: Train Line:['L4', 'L4', 'L4']*  *F-->J:Travel Time:11.0 Travel Route:['F', 'K', 'J']: Train Line:['L2', 'L1']*  *F-->K:Travel Time:5.0 Travel Route:['F', 'K']: Train Line:['L2']*  *F-->L:Travel Time:18.0 Travel Route:['F', 'K', 'J', 'L']: Train Line:['L2', 'L1', 'L4']*  *F-->M:Travel Time:16.0 Travel Route:['F', 'N', 'M']: Train Line:['L2', 'L1']*  *F-->N:Travel Time:9.0 Travel Route:['F', 'N']: Train Line:['L2']*  *F-->O:Travel Time:14.0 Travel Route:['F', 'N', 'O']: Train Line:['L2', 'L2']*  *F-->P:Travel Time:22.0 Travel Route:['F', 'G', 'H', 'I', 'P']: Train Line:['L4', 'L4', 'L4', 'L3']*  *F-->Q:Travel Time:8.0 Travel Route:['F', 'G', 'Q']: Train Line:['L4', 'L1']*  *G-->A:Travel Time:15.0 Travel Route:['G', 'F', 'C', 'B', 'A']: Train Line:['L4', 'L4', 'L4', 'L4']*  *G-->B:Travel Time:12.0 Travel Route:['G', 'F', 'C', 'B']: Train Line:['L4', 'L4', 'L4']*  *G-->C:Travel Time:5.0 Travel Route:['G', 'F', 'C']: Train Line:['L4', 'L4']*  *G-->D:Travel Time:10.0 Travel Route:['G', 'F', 'C', 'D']: Train Line:['L4', 'L4', 'L3']*  *G-->E:Travel Time:14.0 Travel Route:['G', 'F', 'C', 'D', 'E']: Train Line:['L4', 'L4', 'L3', 'L3']*  *G-->F:Travel Time:3.0 Travel Route:['G', 'F']: Train Line:['L4']*  *G-->H:Travel Time:3.0 Travel Route:['G', 'H']: Train Line:['L4']*  *G-->I:Travel Time:6.0 Travel Route:['G', 'H', 'I']: Train Line:['L4', 'L4']*  *G-->J:Travel Time:9.0 Travel Route:['G', 'K', 'J']: Train Line:['L1', 'L1']*  *G-->K:Travel Time:3.0 Travel Route:['G', 'K']: Train Line:['L1']*  *G-->L:Travel Time:16.0 Travel Route:['G', 'K', 'J', 'L']: Train Line:['L1', 'L1', 'L4']*  *G-->M:Travel Time:16.0 Travel Route:['G', 'Q', 'N', 'M']: Train Line:['L1', 'L1', 'L1']*  *G-->N:Travel Time:9.0 Travel Route:['G', 'Q', 'N']: Train Line:['L1', 'L1']*  *G-->O:Travel Time:14.0 Travel Route:['G', 'Q', 'N', 'O']: Train Line:['L1', 'L1', 'L2']*  *G-->P:Travel Time:19.0 Travel Route:['G', 'H', 'I', 'P']: Train Line:['L4', 'L4', 'L3']*  *G-->Q:Travel Time:5.0 Travel Route:['G', 'Q']: Train Line:['L1']*  *H-->A:Travel Time:18.0 Travel Route:['H', 'G', 'F', 'C', 'B', 'A']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4']*  *H-->B:Travel Time:15.0 Travel Route:['H', 'G', 'F', 'C', 'B']: Train Line:['L4', 'L4', 'L4', 'L4']*  *H-->C:Travel Time:8.0 Travel Route:['H', 'G', 'F', 'C']: Train Line:['L4', 'L4', 'L4']*  *H-->D:Travel Time:13.0 Travel Route:['H', 'G', 'F', 'C', 'D']: Train Line:['L4', 'L4', 'L4', 'L3']*  *H-->E:Travel Time:17.0 Travel Route:['H', 'G', 'F', 'C', 'D', 'E']: Train Line:['L4', 'L4', 'L4', 'L3', 'L3']*  *H-->F:Travel Time:6.0 Travel Route:['H', 'G', 'F']: Train Line:['L4', 'L4']*  *H-->G:Travel Time:3.0 Travel Route:['H', 'G']: Train Line:['L4']*  *H-->I:Travel Time:3.0 Travel Route:['H', 'I']: Train Line:['L4']*  *H-->J:Travel Time:10.0 Travel Route:['H', 'K', 'J']: Train Line:['L2', 'L1']*  *H-->K:Travel Time:4.0 Travel Route:['H', 'K']: Train Line:['L2']*  *H-->L:Travel Time:17.0 Travel Route:['H', 'K', 'J', 'L']: Train Line:['L2', 'L1', 'L4']*  *H-->M:Travel Time:19.0 Travel Route:['H', 'G', 'Q', 'N', 'M']: Train Line:['L4', 'L1', 'L1', 'L1']*  *H-->N:Travel Time:12.0 Travel Route:['H', 'G', 'Q', 'N']: Train Line:['L4', 'L1', 'L1']*  *H-->O:Travel Time:12.0 Travel Route:['H', 'O']: Train Line:['L2']*  *H-->P:Travel Time:16.0 Travel Route:['H', 'I', 'P']: Train Line:['L4', 'L3']*  *H-->Q:Travel Time:8.0 Travel Route:['H', 'G', 'Q']: Train Line:['L4', 'L1']*  *I-->A:Travel Time:21.0 Travel Route:['I', 'H', 'G', 'F', 'C', 'B', 'A']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4', 'L4']*  *I-->B:Travel Time:18.0 Travel Route:['I', 'H', 'G', 'F', 'C', 'B']: Train Line:['L4', 'L4', 'L4', 'L4', 'L4']*  *I-->C:Travel Time:11.0 Travel Route:['I', 'H', 'G', 'F', 'C']: Train Line:['L4', 'L4', 'L4', 'L4']*  *I-->D:Travel Time:16.0 Travel Route:['I', 'H', 'G', 'F', 'C', 'D']: Train Line:['L4', 'L4', 'L4', 'L4', 'L3']*  *I-->E:Travel Time:20.0 Travel Route:['I', 'H', 'G', 'F', 'C', 'D', 'E']: Train Line:['L4', 'L4', 'L4', 'L4', 'L3', 'L3']*  *I-->F:Travel Time:9.0 Travel Route:['I', 'H', 'G', 'F']: Train Line:['L4', 'L4', 'L4']*  *I-->G:Travel Time:6.0 Travel Route:['I', 'H', 'G']: Train Line:['L4', 'L4']*  *I-->H:Travel Time:3.0 Travel Route:['I', 'H']: Train Line:['L4']*  *I-->J:Travel Time:9.0 Travel Route:['I', 'J']: Train Line:['L4']*  *I-->K:Travel Time:7.0 Travel Route:['I', 'H', 'K']: Train Line:['L4', 'L2']*  *I-->L:Travel Time:16.0 Travel Route:['I', 'J', 'L']: Train Line:['L4', 'L4']*  *I-->M:Travel Time:22.0 Travel Route:['I', 'H', 'G', 'Q', 'N', 'M']: Train Line:['L4', 'L4', 'L1', 'L1', 'L1']*  *I-->N:Travel Time:15.0 Travel Route:['I', 'H', 'G', 'Q', 'N']: Train Line:['L4', 'L4', 'L1', 'L1']*  *I-->O:Travel Time:15.0 Travel Route:['I', 'H', 'O']: Train Line:['L4', 'L2']*  *I-->P:Travel Time:13.0 Travel Route:['I', 'P']: Train Line:['L3']*  *I-->Q:Travel Time:11.0 Travel Route:['I', 'H', 'G', 'Q']: Train Line:['L4', 'L4', 'L1']*  *J-->A:Travel Time:23.0 Travel Route:['J', 'K', 'F', 'C', 'B', 'A']: Train Line:['L1', 'L2', 'L4', 'L4', 'L4']*  *J-->B:Travel Time:20.0 Travel Route:['J', 'K', 'F', 'C', 'B']: Train Line:['L1', 'L2', 'L4', 'L4']*  *J-->C:Travel Time:13.0 Travel Route:['J', 'K', 'F', 'C']: Train Line:['L1', 'L2', 'L4']*  *J-->D:Travel Time:18.0 Travel Route:['J', 'K', 'F', 'C', 'D']: Train Line:['L1', 'L2', 'L4', 'L3']*  *J-->E:Travel Time:22.0 Travel Route:['J', 'K', 'F', 'C', 'D', 'E']: Train Line:['L1', 'L2', 'L4', 'L3', 'L3']*  *J-->F:Travel Time:11.0 Travel Route:['J', 'K', 'F']: Train Line:['L1', 'L2']*  *J-->G:Travel Time:9.0 Travel Route:['J', 'K', 'G']: Train Line:['L1', 'L1']*  *J-->H:Travel Time:10.0 Travel Route:['J', 'K', 'H']: Train Line:['L1', 'L2']*  *J-->I:Travel Time:9.0 Travel Route:['J', 'I']: Train Line:['L4']*  *J-->K:Travel Time:6.0 Travel Route:['J', 'K']: Train Line:['L1']*  *J-->L:Travel Time:7.0 Travel Route:['J', 'L']: Train Line:['L4']*  *J-->M:Travel Time:25.0 Travel Route:['J', 'K', 'G', 'Q', 'N', 'M']: Train Line:['L1', 'L1', 'L1', 'L1', 'L1']*  *J-->N:Travel Time:18.0 Travel Route:['J', 'K', 'G', 'Q', 'N']: Train Line:['L1', 'L1', 'L1', 'L1']*  *J-->O:Travel Time:22.0 Travel Route:['J', 'K', 'H', 'O']: Train Line:['L1', 'L2', 'L2']*  *J-->P:Travel Time:22.0 Travel Route:['J', 'I', 'P']: Train Line:['L4', 'L3']*  *J-->Q:Travel Time:14.0 Travel Route:['J', 'K', 'G', 'Q']: Train Line:['L1', 'L1', 'L1']*  *K-->A:Travel Time:17.0 Travel Route:['K', 'F', 'C', 'B', 'A']: Train Line:['L2', 'L4', 'L4', 'L4']*  *K-->B:Travel Time:14.0 Travel Route:['K', 'F', 'C', 'B']: Train Line:['L2', 'L4', 'L4']*  *K-->C:Travel Time:7.0 Travel Route:['K', 'F', 'C']: Train Line:['L2', 'L4']*  *K-->D:Travel Time:12.0 Travel Route:['K', 'F', 'C', 'D']: Train Line:['L2', 'L4', 'L3']*  *K-->E:Travel Time:16.0 Travel Route:['K', 'F', 'C', 'D', 'E']: Train Line:['L2', 'L4', 'L3', 'L3']*  *K-->F:Travel Time:5.0 Travel Route:['K', 'F']: Train Line:['L2']*  *K-->G:Travel Time:3.0 Travel Route:['K', 'G']: Train Line:['L1']*  *K-->H:Travel Time:4.0 Travel Route:['K', 'H']: Train Line:['L2']*  *K-->I:Travel Time:7.0 Travel Route:['K', 'H', 'I']: Train Line:['L2', 'L4']*  *K-->J:Travel Time:6.0 Travel Route:['K', 'J']: Train Line:['L1']*  *K-->L:Travel Time:13.0 Travel Route:['K', 'J', 'L']: Train Line:['L1', 'L4']*  *K-->M:Travel Time:19.0 Travel Route:['K', 'G', 'Q', 'N', 'M']: Train Line:['L1', 'L1', 'L1', 'L1']*  *K-->N:Travel Time:12.0 Travel Route:['K', 'G', 'Q', 'N']: Train Line:['L1', 'L1', 'L1']*  *K-->O:Travel Time:16.0 Travel Route:['K', 'H', 'O']: Train Line:['L2', 'L2']*  *K-->P:Travel Time:20.0 Travel Route:['K', 'H', 'I', 'P']: Train Line:['L2', 'L4', 'L3']*  *K-->Q:Travel Time:8.0 Travel Route:['K', 'G', 'Q']: Train Line:['L1', 'L1']*  *L-->A:Travel Time:30.0 Travel Route:['L', 'J', 'K', 'F', 'C', 'B', 'A']: Train Line:['L4', 'L1', 'L2', 'L4', 'L4', 'L4']*  *L-->B:Travel Time:27.0 Travel Route:['L', 'J', 'K', 'F', 'C', 'B']: Train Line:['L4', 'L1', 'L2', 'L4', 'L4']*  *L-->C:Travel Time:20.0 Travel Route:['L', 'J', 'K', 'F', 'C']: Train Line:['L4', 'L1', 'L2', 'L4']*  *L-->D:Travel Time:25.0 Travel Route:['L', 'J', 'K', 'F', 'C', 'D']: Train Line:['L4', 'L1', 'L2', 'L4', 'L3']*  *L-->E:Travel Time:29.0 Travel Route:['L', 'J', 'K', 'F', 'C', 'D', 'E']: Train Line:['L4', 'L1', 'L2', 'L4', 'L3', 'L3']*  *L-->F:Travel Time:18.0 Travel Route:['L', 'J', 'K', 'F']: Train Line:['L4', 'L1', 'L2']*  *L-->G:Travel Time:16.0 Travel Route:['L', 'J', 'K', 'G']: Train Line:['L4', 'L1', 'L1']*  *L-->H:Travel Time:17.0 Travel Route:['L', 'J', 'K', 'H']: Train Line:['L4', 'L1', 'L2']*  *L-->I:Travel Time:16.0 Travel Route:['L', 'J', 'I']: Train Line:['L4', 'L4']*  *L-->J:Travel Time:7.0 Travel Route:['L', 'J']: Train Line:['L4']*  *L-->K:Travel Time:13.0 Travel Route:['L', 'J', 'K']: Train Line:['L4', 'L1']*  *L-->M:Travel Time:32.0 Travel Route:['L', 'J', 'K', 'G', 'Q', 'N', 'M']: Train Line:['L4', 'L1', 'L1', 'L1', 'L1', 'L1']*  *L-->N:Travel Time:25.0 Travel Route:['L', 'J', 'K', 'G', 'Q', 'N']: Train Line:['L4', 'L1', 'L1', 'L1', 'L1']*  *L-->O:Travel Time:29.0 Travel Route:['L', 'J', 'K', 'H', 'O']: Train Line:['L4', 'L1', 'L2', 'L2']*  *L-->P:Travel Time:29.0 Travel Route:['L', 'J', 'I', 'P']: Train Line:['L4', 'L4', 'L3']*  *L-->Q:Travel Time:21.0 Travel Route:['L', 'J', 'K', 'G', 'Q']: Train Line:['L4', 'L1', 'L1', 'L1']*  *M-->A:Travel Time:28.0 Travel Route:['M', 'N', 'F', 'C', 'B', 'A']: Train Line:['L1', 'L2', 'L4', 'L4', 'L4']*  *M-->B:Travel Time:25.0 Travel Route:['M', 'N', 'F', 'C', 'B']: Train Line:['L1', 'L2', 'L4', 'L4']*  *M-->C:Travel Time:18.0 Travel Route:['M', 'N', 'F', 'C']: Train Line:['L1', 'L2', 'L4']*  *M-->D:Travel Time:23.0 Travel Route:['M', 'N', 'F', 'C', 'D']: Train Line:['L1', 'L2', 'L4', 'L3']*  *M-->E:Travel Time:27.0 Travel Route:['M', 'N', 'F', 'C', 'D', 'E']: Train Line:['L1', 'L2', 'L4', 'L3', 'L3']*  *M-->F:Travel Time:16.0 Travel Route:['M', 'N', 'F']: Train Line:['L1', 'L2']*  *M-->G:Travel Time:16.0 Travel Route:['M', 'N', 'Q', 'G']: Train Line:['L1', 'L1', 'L1']*  *M-->H:Travel Time:19.0 Travel Route:['M', 'N', 'Q', 'G', 'H']: Train Line:['L1', 'L1', 'L1', 'L4']*  *M-->I:Travel Time:22.0 Travel Route:['M', 'N', 'Q', 'G', 'H', 'I']: Train Line:['L1', 'L1', 'L1', 'L4', 'L4']*  *M-->J:Travel Time:25.0 Travel Route:['M', 'N', 'Q', 'G', 'K', 'J']: Train Line:['L1', 'L1', 'L1', 'L1', 'L1']*  *M-->K:Travel Time:19.0 Travel Route:['M', 'N', 'Q', 'G', 'K']: Train Line:['L1', 'L1', 'L1', 'L1']*  *M-->L:Travel Time:32.0 Travel Route:['M', 'N', 'Q', 'G', 'K', 'J', 'L']: Train Line:['L1', 'L1', 'L1', 'L1', 'L1', 'L4']*  *M-->N:Travel Time:7.0 Travel Route:['M', 'N']: Train Line:['L1']*  *M-->O:Travel Time:12.0 Travel Route:['M', 'N', 'O']: Train Line:['L1', 'L2']*  *M-->P:Travel Time:35.0 Travel Route:['M', 'N', 'Q', 'G', 'H', 'I', 'P']: Train Line:['L1', 'L1', 'L1', 'L4', 'L4', 'L3']*  *M-->Q:Travel Time:11.0 Travel Route:['M', 'N', 'Q']: Train Line:['L1', 'L1']*  *N-->A:Travel Time:21.0 Travel Route:['N', 'F', 'C', 'B', 'A']: Train Line:['L2', 'L4', 'L4', 'L4']*  *N-->B:Travel Time:18.0 Travel Route:['N', 'F', 'C', 'B']: Train Line:['L2', 'L4', 'L4']*  *N-->C:Travel Time:11.0 Travel Route:['N', 'F', 'C']: Train Line:['L2', 'L4']*  *N-->D:Travel Time:16.0 Travel Route:['N', 'F', 'C', 'D']: Train Line:['L2', 'L4', 'L3']*  *N-->E:Travel Time:20.0 Travel Route:['N', 'F', 'C', 'D', 'E']: Train Line:['L2', 'L4', 'L3', 'L3']*  *N-->F:Travel Time:9.0 Travel Route:['N', 'F']: Train Line:['L2']*  *N-->G:Travel Time:9.0 Travel Route:['N', 'Q', 'G']: Train Line:['L1', 'L1']*  *N-->H:Travel Time:12.0 Travel Route:['N', 'Q', 'G', 'H']: Train Line:['L1', 'L1', 'L4']*  *N-->I:Travel Time:15.0 Travel Route:['N', 'Q', 'G', 'H', 'I']: Train Line:['L1', 'L1', 'L4', 'L4']*  *N-->J:Travel Time:18.0 Travel Route:['N', 'Q', 'G', 'K', 'J']: Train Line:['L1', 'L1', 'L1', 'L1']*  *N-->K:Travel Time:12.0 Travel Route:['N', 'Q', 'G', 'K']: Train Line:['L1', 'L1', 'L1']*  *N-->L:Travel Time:25.0 Travel Route:['N', 'Q', 'G', 'K', 'J', 'L']: Train Line:['L1', 'L1', 'L1', 'L1', 'L4']*  *N-->M:Travel Time:7.0 Travel Route:['N', 'M']: Train Line:['L1']*  *N-->O:Travel Time:5.0 Travel Route:['N', 'O']: Train Line:['L2']*  *N-->P:Travel Time:28.0 Travel Route:['N', 'Q', 'G', 'H', 'I', 'P']: Train Line:['L1', 'L1', 'L4', 'L4', 'L3']*  *N-->Q:Travel Time:4.0 Travel Route:['N', 'Q']: Train Line:['L1']*  *O-->A:Travel Time:26.0 Travel Route:['O', 'N', 'F', 'C', 'B', 'A']: Train Line:['L2', 'L2', 'L4', 'L4', 'L4']*  *O-->B:Travel Time:23.0 Travel Route:['O', 'N', 'F', 'C', 'B']: Train Line:['L2', 'L2', 'L4', 'L4']*  *O-->C:Travel Time:16.0 Travel Route:['O', 'N', 'F', 'C']: Train Line:['L2', 'L2', 'L4']*  *O-->D:Travel Time:21.0 Travel Route:['O', 'N', 'F', 'C', 'D']: Train Line:['L2', 'L2', 'L4', 'L3']*  *O-->E:Travel Time:25.0 Travel Route:['O', 'N', 'F', 'C', 'D', 'E']: Train Line:['L2', 'L2', 'L4', 'L3', 'L3']*  *O-->F:Travel Time:14.0 Travel Route:['O', 'N', 'F']: Train Line:['L2', 'L2']*  *O-->G:Travel Time:14.0 Travel Route:['O', 'N', 'Q', 'G']: Train Line:['L2', 'L1', 'L1']*  *O-->H:Travel Time:12.0 Travel Route:['O', 'H']: Train Line:['L2']*  *O-->I:Travel Time:15.0 Travel Route:['O', 'H', 'I']: Train Line:['L2', 'L4']*  *O-->J:Travel Time:22.0 Travel Route:['O', 'H', 'K', 'J']: Train Line:['L2', 'L2', 'L1']*  *O-->K:Travel Time:16.0 Travel Route:['O', 'H', 'K']: Train Line:['L2', 'L2']*  *O-->L:Travel Time:29.0 Travel Route:['O', 'H', 'K', 'J', 'L']: Train Line:['L2', 'L2', 'L1', 'L4']*  *O-->M:Travel Time:12.0 Travel Route:['O', 'N', 'M']: Train Line:['L2', 'L1']*  *O-->N:Travel Time:5.0 Travel Route:['O', 'N']: Train Line:['L2']*  *O-->P:Travel Time:28.0 Travel Route:['O', 'H', 'I', 'P']: Train Line:['L2', 'L4', 'L3']*  *O-->Q:Travel Time:9.0 Travel Route:['O', 'N', 'Q']: Train Line:['L2', 'L1']*  *P-->A:Travel Time:34.0 Travel Route:['P', 'I', 'H', 'G', 'F', 'C', 'B', 'A']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4', 'L4', 'L4']*  *P-->B:Travel Time:31.0 Travel Route:['P', 'I', 'H', 'G', 'F', 'C', 'B']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4', 'L4']*  *P-->C:Travel Time:24.0 Travel Route:['P', 'I', 'H', 'G', 'F', 'C']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4']*  *P-->D:Travel Time:29.0 Travel Route:['P', 'I', 'H', 'G', 'F', 'C', 'D']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4', 'L3']*  *P-->E:Travel Time:33.0 Travel Route:['P', 'I', 'H', 'G', 'F', 'C', 'D', 'E']: Train Line:['L3', 'L4', 'L4', 'L4', 'L4', 'L3', 'L3']*  *P-->F:Travel Time:22.0 Travel Route:['P', 'I', 'H', 'G', 'F']: Train Line:['L3', 'L4', 'L4', 'L4']*  *P-->G:Travel Time:19.0 Travel Route:['P', 'I', 'H', 'G']: Train Line:['L3', 'L4', 'L4']*  *P-->H:Travel Time:16.0 Travel Route:['P', 'I', 'H']: Train Line:['L3', 'L4']*  *P-->I:Travel Time:13.0 Travel Route:['P', 'I']: Train Line:['L3']*  *P-->J:Travel Time:22.0 Travel Route:['P', 'I', 'J']: Train Line:['L3', 'L4']*  *P-->K:Travel Time:20.0 Travel Route:['P', 'I', 'H', 'K']: Train Line:['L3', 'L4', 'L2']*  *P-->L:Travel Time:29.0 Travel Route:['P', 'I', 'J', 'L']: Train Line:['L3', 'L4', 'L4']*  *P-->M:Travel Time:35.0 Travel Route:['P', 'I', 'H', 'G', 'Q', 'N', 'M']: Train Line:['L3', 'L4', 'L4', 'L1', 'L1', 'L1']*  *P-->N:Travel Time:28.0 Travel Route:['P', 'I', 'H', 'G', 'Q', 'N']: Train Line:['L3', 'L4', 'L4', 'L1', 'L1']*  *P-->O:Travel Time:28.0 Travel Route:['P', 'I', 'H', 'O']: Train Line:['L3', 'L4', 'L2']*  *P-->Q:Travel Time:24.0 Travel Route:['P', 'I', 'H', 'G', 'Q']: Train Line:['L3', 'L4', 'L4', 'L1']*  *Q-->A:Travel Time:20.0 Travel Route:['Q', 'G', 'F', 'C', 'B', 'A']: Train Line:['L1', 'L4', 'L4', 'L4', 'L4']*  *Q-->B:Travel Time:17.0 Travel Route:['Q', 'G', 'F', 'C', 'B']: Train Line:['L1', 'L4', 'L4', 'L4']*  *Q-->C:Travel Time:10.0 Travel Route:['Q', 'G', 'F', 'C']: Train Line:['L1', 'L4', 'L4']*  *Q-->D:Travel Time:15.0 Travel Route:['Q', 'G', 'F', 'C', 'D']: Train Line:['L1', 'L4', 'L4', 'L3']*  *Q-->E:Travel Time:19.0 Travel Route:['Q', 'G', 'F', 'C', 'D', 'E']: Train Line:['L1', 'L4', 'L4', 'L3', 'L3']*  *Q-->F:Travel Time:8.0 Travel Route:['Q', 'G', 'F']: Train Line:['L1', 'L4']*  *Q-->G:Travel Time:5.0 Travel Route:['Q', 'G']: Train Line:['L1']*  *Q-->H:Travel Time:8.0 Travel Route:['Q', 'G', 'H']: Train Line:['L1', 'L4']*  *Q-->I:Travel Time:11.0 Travel Route:['Q', 'G', 'H', 'I']: Train Line:['L1', 'L4', 'L4']*  *Q-->J:Travel Time:14.0 Travel Route:['Q', 'G', 'K', 'J']: Train Line:['L1', 'L1', 'L1']*  *Q-->K:Travel Time:8.0 Travel Route:['Q', 'G', 'K']: Train Line:['L1', 'L1']*  *Q-->L:Travel Time:21.0 Travel Route:['Q', 'G', 'K', 'J', 'L']: Train Line:['L1', 'L1', 'L1', 'L4']*  *Q-->M:Travel Time:11.0 Travel Route:['Q', 'N', 'M']: Train Line:['L1', 'L1']*  *Q-->N:Travel Time:4.0 Travel Route:['Q', 'N']: Train Line:['L1']*  *Q-->O:Travel Time:9.0 Travel Route:['Q', 'N', 'O']: Train Line:['L1', 'L2']*  *Q-->P:Travel Time:24.0 Travel Route:['Q', 'G', 'H', 'I', 'P']: Train Line:['L1', 'L4', 'L4', 'L3']* |
|  |
| C. decision variables to determine how many trains will be required for each line to meet passenger demand [853-880] |
|  |
| constraints that ensure passenger demand is met on the whole network [881-990] |
|  |
|  |
|  |
|  |
| objective function to minimise the number of trains operated on the network [995-1015] |
|  |
| Solve the linear program and determine how many trains are required  determine how many trains are required per line [1016-1028] |
|  |
| *Total train required:87.0*  *L1:17.0*  *L2: 13.0, 10.0*  *L3:29.0*  *L4:18.0* |