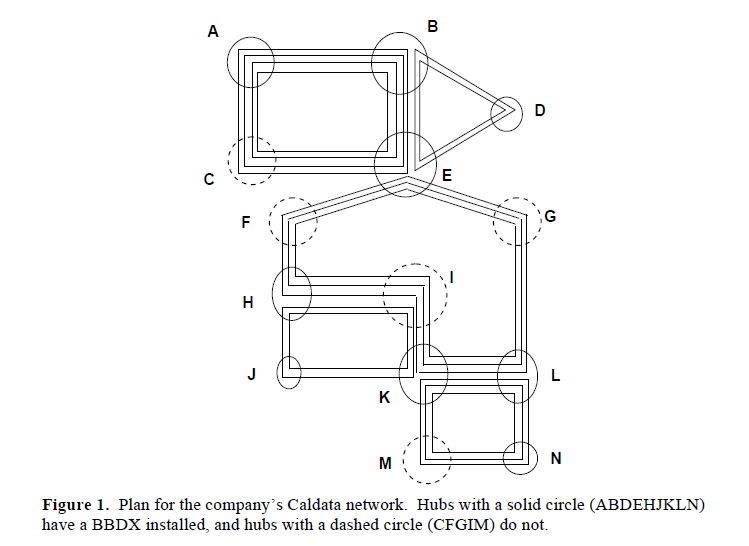
**SONET Telecommunication Network Design**



**Caldata Lower Bound:**

We started our analysis of the lower bound with a few basic ideas. The cost for ADMs contributed the most on the objective function as compared to the flow cost. So the team decided to figure out minimum number of ADMs that would require to satisfy all the flow in the network.

At first, we knew that there was flow going in and out of every hub/city node. This implied at least one ADM to be installed at every hub which turns out to be 14 ADMs. We were able to run the caldata network for the optimal solution, so we knew that 33 were the minimum number of ADMs required. So we brainstormed on ideas to increase the number of ADMs.

In our second attempt, we realized that the ADMs capacity to handle flow in both the direction is 48000. We added up all the flows coming in and going out of each hub/city node and divide it by 48000 to get the minimum ADMs required at the particular hub/city node. Doing this, we were able to increase the number of ADMs to 28.

After this we observed and compared the ADMs at every hub/city node with the optimal solution. We found that our lower bound ADMs were short compared to the optimal at hub/city nodes where there was junction between two cycles. In the caldata network, there were junctions at B, E, H, K and L. If the data had to jump at these junctions between cycles, there has to be at least one ADM installed in all the cycles that were connected by that hub junction. This would mean that there has to be minimum 2 ADMs at B, H and L hubs and 3 ADMs at hubs E and K. Implementing this took our total ADMs in the caldata network to 31 leaving a deficit of 2 ADMs at node E where we already had a decision of installing 5 ADMs. We decided to split node E into three different sub-nodes connecting 3 different cycles. We sent all the data coming from cycle ABEC to the left sub-node at E, all data from cycle BDE sent to right sub-node E and all data from the bottom caldata network to bottom sub-node E. Dividing these flows by ADM capacity of 48000 gave us 3 ADMs at the left sub-node, and 2 ADMs each at the right and bottom sub-node E, giving us a total of 7 ADMs at hub/city node E and increasing our ADM number for the caldata network to 33 ADMs (*refer appendix K for details*)

Once we had the optimal minimum number of ADMs, the next step was to add the flow cost to the objective function. For this, we deleted the ADM cost function from the objective in the AMPL code and ran it for optimality. With this we got the minimum cost flow for the network to be $4,223,000. We further improved this minimum cost for the flow by running the original model with relaxing the integer constraints. This gave us continuous values for the adm variable. Adding these ADM variable outputs, multiplying by $1,000,000 and then subtracting this from the Total Cost gave us a much-increased value for minimum cost of $4,695,005 for flow through the network.

The above heuristic ideas gave us 33 ADMs with cost of $33,000,000 and the minimum cost of $4,695,005 for the flow. Adding these costs, we got our best lower bound of $37,695,005.

**Caldata Upper Bound:**

Luckily, trying to find a good upper bound came much quicker than our attempts to finding the lower bounds. Our initial thought was to split up the networks into 2 data files. The top one includes the cycles ABEC and BED with the bottom file including cycles FEGLKIH, HJKI, AND KLNM. Our first attempt ended up being a lower bound since we didn’t include the flows from one side of E going to the other side of E. This first attempt is shown in Appendix E.

Our next and best attempt, shown in Appendix F, was doing the same thing except adding in all the supply/demand. If there was data from the top network (excluding E) going to the bottom network (also excluding E), we sent all the data through E and used that as the demand node. Then in the bottom network, we would take all the data and have E supply it to all the other demand nodes in the bottom network. We then do the same method for the bottom network data file, but in reverse and using the demand table. This allowed all of the data to flow through exactly what it would normally be flowing through if we ran the full model completely. The top data file cost was $14,505,000 and the bottom cost was $22,814,000. This however isn’t our upper bound total cost because it doesn’t include the cost of using the BBDX to jump networks ($4 per data unit). The other $4 for ADM cost is already accounted for in the 2 separate models since E is taking on the data as the supply and demand node. So we tallied up the demand that was jumping networks at E, which ended up being 92,000 units jumping up and 11,000 units jumping down. So the jumping cost at E was 4\*(92000+11000)=$412,000. When we summed up these 3 costs, we got $37,731,000, which ended up being the optimal solution!

Our final step to prove this was an upper bound was to prove that this solution was feasible because a solution that has the same cost as the optimal solution needs to be feasible to be considered an upper bound.

**Feasibility proof for the upper bound:**

As we were able to run the model for the split networks, the output obtained from it is already feasible. We can see from the displayed flow variables that there is still unused capacities in the arcs which have capacities of 24000 for the caldata and 48000 for the barry network (*check appendix M for the flow values*). So when we include the jump flows, the current solution already has unused capacities for the arcs which can incorporate the jumps flow and retaining the feasibility of the solution.

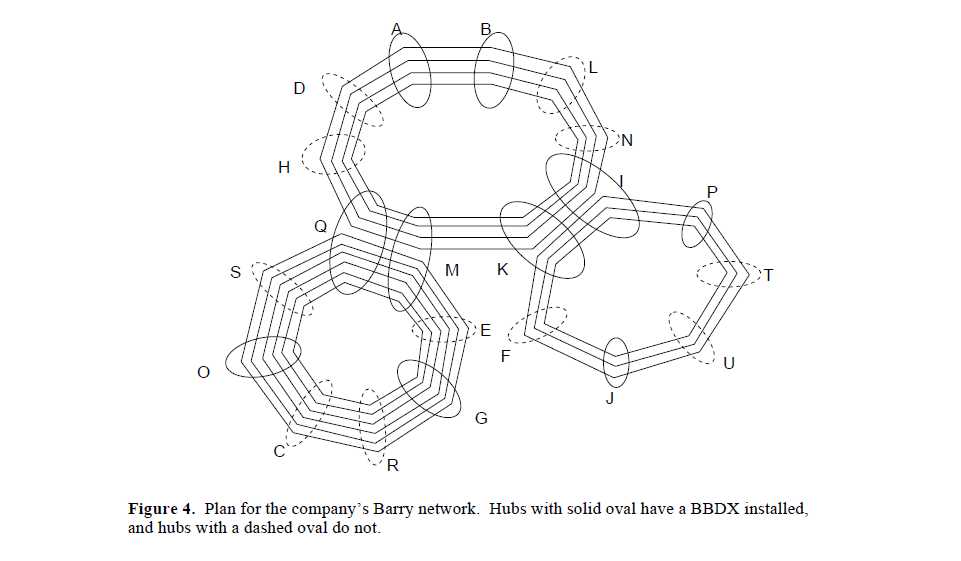
**Caldata Network Optimality Gap:**

(UB-LB)/UB = (37,731,000-37,695,005)/37,731,000 = 0.00095399

So our Caldata Network Optimality Gap is 0.095%.

**Caldata and Barry Differences:**

The layout of the networks are different, the arc capacities in the Barry network is double that of the Caldata network arcs, the cost of flow on the fibers are different for the networks, the supply/demand for the hubs are different, and different hubs have BBDX installed. These differences can all be changed pretty easily in the data files. There are also 2 BBDX nodes between the networks in the Barry network, which will be worked through differently than the Caldata network.



**Barry Lower Bound:**

We applied the same heuristics for the Barry network as we did to the caldata network. At first, we obtained a minimum ADMs as 21. Proceeding further with similar ideas as for caldata, we were able to improve the number of ADMs until 41. After this we split the junctions nodes Q, M, K and I into subnodes and sending all flows to these nodes, we were able to come up with 3 ADMs at hub/city node Q, 4 ADMs at hub/city node M, 3 ADMs at hub/city node K and 3 ADMs at hub/city node I totaling our ADM number for the Barry network to be 48. We knew this was the minimum number of ADMs as we were able to run the model for Barry network by splitting the network into three different networks where we obtained the total ADMs to be 48 (refer appendix L for details)

After this, our next step was to calculate the minimum cost of flow to add up to the ADM cost to find our lower bound. Again, we deleted the ADM cost function from the objective and ran the model to get minimum cost for flow through the network which would assume ADMs installed at all the possible locations. We had the minimum cost as $11,791,100. We improved his minimum cost further as we ran the model with relaxed integrality constraints to get continuous values for the ADM variables. We added up these values and multiplied by 1,000,000 to get total the adm cost. Then we subtracted this adm cost from the Total\_Cost to find an improved value of $1,223,6551.63 for the minimum cost for flow.

So our final lower bound for the Barry network is,

ADM cost + Minimum Cost of Flow = 48,000,000+1,223,6551 = $60,236,551

**Barry Upper Bound:**

For the Barry Network, we initially did the same thing as the Caldata and split up the network into 3 data files; Top (ABLNIKMQHD), Left (QMEGRCOS), and Right (KIPTUJF) and only sent the supply and demand within a network as shown in Appendix I. As mentioned above, this wouldn’t be taking into account the data that needs to jump networks. In our 2nd attempt, shown in Appendix J, we used the same logic as we did with the Caldata network with the only 2 differences being there are 2 jumping hubs between every 2 of the 3 networks except Left and Right.

The other difference is data can jump twice through all 3 data files instead of just through 1 jump between 2 data files. We decided to send half of the data through Q and the other half through M for any data jumping from Top to Left or Left to Top. The same methodology goes for Top to Right and Right to Top. Regardless of where it was going out of the network, it would be sent to one or 2 of the connecting hubs (Q,M,K, or I). For example, if data had to go from G to P, the left data file would have half the supply go from G to Q and the other half go from G to M. The top data file had the data flow from Q to I and M to K. Finally, the right file had all the data initially coming from G (destined for P) that are currently in K and I go to P.

The top data file cost was $20,931,000, the right cost was $13,259,600, and the left cost was $25,334,700. Again, this isn’t our upper bound total cost because it doesn’t include the cost of using the BBDX to jump networks ($4 per data unit). So we tallied all data that needed to jump once and multiplied that by $4. Any demand that needed to jump twice was multiplied by $8.

So the total jumping cost was 4\*(35000+142000+31000+11000)+8\*(92000+48000)=$1,996,000. Adding up all the costs, we get a total Barry network upper bound cost of $61,521,300. Again, our final step to prove this was an upper bound was to prove that this solution was feasible, which it was.

**Barry Network Optimality Gap:**

(UB-LB)/UB = (61,521,300-60,236,551)/61,521,300 = 0.02088299

So our Barry Network Optimality Gap is 2.088%

Appendices:

Appendix A: AMPL Output of running full Caldata network with binary constraint relaxed

Appendix B: AMPL Output of running Caldata network Min Cost Flow Problem

Appendix C: AMPL Output of running full Caldata network and stopping after 10 mins of run time

Appendix D: AMPL Output of running full Caldata network to completion

Appendix E: AMPL Output of running Caldata network split into 2 data files split at Hub E (excludes jump flows)

Appendix F: AMPL Output of running Caldata network split into 2 data files split at Hub E (includes jump flows)

Appendix G: AMPL Output of running Barry network Min Cost Flow Problem

Appendix H: AMPL Output of running full Barry network with binary constraint relaxed

Appendix I: AMPL Output of Barry network split 3 ways with flow through networks (excludes jump flows)

Appendix J: AMPL Output of Barry network split 3 ways with flow through networks (includes jump flows)

Appendix K: Excel table showing sum of flows and calculation of minimum ADMs for Caldata network.

Appendix L: Excel table showing sum of flows and calculation of minimum ADMs for Barry network.

Appendix A: AMPL Output of running full Caldata network with binary constraint relaxed

Total\_Cost = 9571740

adm [\*] :=

ABEC\_A\_1 0.208333 BDE\_E\_2 0.00763889 EGLKIHF\_L\_3 0.0381944

ABEC\_A\_2 0.238542 EGLKIHF\_E\_1 0.046875 HIKJ\_H\_1 0.0157986

ABEC\_A\_3 0.172917 EGLKIHF\_E\_2 0.046875 HIKJ\_H\_2 0.0675347

ABEC\_A\_4 0.255208 EGLKIHF\_E\_3 0.046875 HIKJ\_I\_1 0

ABEC\_B\_1 0.208333 EGLKIHF\_F\_1 0.0847222 HIKJ\_I\_2 0

ABEC\_B\_2 0.238542 EGLKIHF\_F\_2 0.0201389 HIKJ\_J\_1 0.166667

ABEC\_B\_3 0.172917 EGLKIHF\_F\_3 0.0201389 HIKJ\_J\_2 0.25

ABEC\_B\_4 0.171875 EGLKIHF\_G\_1 0.015625 HIKJ\_K\_1 0.0833333

ABEC\_C\_1 0.000694444 EGLKIHF\_G\_2 0.046875 HIKJ\_K\_2 0.0833333

ABEC\_C\_2 0 EGLKIHF\_G\_3 0 KLNM\_K\_1 0.0833333

ABEC\_C\_3 0.0201389 EGLKIHF\_H\_1 0.0157986 KLNM\_K\_2 0.0833333

ABEC\_C\_4 0 EGLKIHF\_H\_2 0.0157986 KLNM\_K\_3 0.0833333

ABEC\_E\_1 0.046875 EGLKIHF\_H\_3 0.0100694 KLNM\_L\_1 0.0381944

ABEC\_E\_2 0.046875 EGLKIHF\_I\_1 0.0208333 KLNM\_L\_2 0.0381944

ABEC\_E\_3 0.046875 EGLKIHF\_I\_2 0 KLNM\_L\_3 0.0381944

ABEC\_E\_4 0.046875 EGLKIHF\_I\_3 0 KLNM\_M\_1 0

BDE\_B\_1 0.0604167 EGLKIHF\_K\_1 0.0503472 KLNM\_M\_2 0.0416667

BDE\_B\_2 0.0229167 EGLKIHF\_K\_2 0.0842014 KLNM\_M\_3 0

BDE\_D\_1 0.28125 EGLKIHF\_K\_3 0.115451 KLNM\_N\_1 0.206597

BDE\_D\_2 0.114583 EGLKIHF\_L\_1 0.0381944 KLNM\_N\_2 0.177083

BDE\_E\_1 0.0201389 EGLKIHF\_L\_2 0.0381944 KLNM\_N\_3 0.282986

Appendix B: AMPL Output of running Caldata network Min Cost Flow Problem

Total\_Cost = 9571740

adm [\*] :=

ABEC\_A\_1 1 BDE\_E\_2 1 EGLKIHF\_L\_3 1

ABEC\_A\_2 1 EGLKIHF\_E\_1 1 HIKJ\_H\_1 1

ABEC\_A\_3 1 EGLKIHF\_E\_2 1 HIKJ\_H\_2 1

ABEC\_A\_4 1 EGLKIHF\_E\_3 1 HIKJ\_I\_1 1

ABEC\_B\_1 1 EGLKIHF\_F\_1 1 HIKJ\_I\_2 1

ABEC\_B\_2 1 EGLKIHF\_F\_2 1 HIKJ\_J\_1 1

ABEC\_B\_3 1 EGLKIHF\_F\_3 1 HIKJ\_J\_2 1

ABEC\_B\_4 1 EGLKIHF\_G\_1 1 HIKJ\_K\_1 1

ABEC\_C\_1 1 EGLKIHF\_G\_2 1 HIKJ\_K\_2 1

ABEC\_C\_2 1 EGLKIHF\_G\_3 1 KLNM\_K\_1 1

ABEC\_C\_3 1 EGLKIHF\_H\_1 1 KLNM\_K\_2 1

ABEC\_C\_4 1 EGLKIHF\_H\_2 1 KLNM\_K\_3 1

ABEC\_E\_1 1 EGLKIHF\_H\_3 1 KLNM\_L\_1 1

ABEC\_E\_2 1 EGLKIHF\_I\_1 1 KLNM\_L\_2 1

ABEC\_E\_3 1 EGLKIHF\_I\_2 1 KLNM\_L\_3 1

ABEC\_E\_4 1 EGLKIHF\_I\_3 1 KLNM\_M\_1 1

BDE\_B\_1 1 EGLKIHF\_K\_1 1 KLNM\_M\_2 1

BDE\_B\_2 1 EGLKIHF\_K\_2 1 KLNM\_M\_3 1

BDE\_D\_1 1 EGLKIHF\_K\_3 1 KLNM\_N\_1 1

BDE\_D\_2 1 EGLKIHF\_L\_1 1 KLNM\_N\_2 1

BDE\_E\_1 1 EGLKIHF\_L\_2 1 KLNM\_N\_3 1

63 ADMs

Appendix C: AMPL Output of running full Caldata network and stopping after 10 mins of run time

Total\_Cost = 37825000

adm [\*] :=

ABEC\_A\_1 1 ABEC\_E\_2 0 EGLKIHF\_F\_2 0 EGLKIHF\_K\_3 0 KLNM\_K\_2 1

ABEC\_A\_2 1 ABEC\_E\_3 1 EGLKIHF\_F\_3 0 EGLKIHF\_L\_1 0 KLNM\_K\_3 1

ABEC\_A\_3 1 ABEC\_E\_4 1 EGLKIHF\_G\_1 1 EGLKIHF\_L\_2 0 KLNM\_L\_1 1

ABEC\_A\_4 0 BDE\_B\_1 1 EGLKIHF\_G\_2 0 EGLKIHF\_L\_3 1 KLNM\_L\_2 0

ABEC\_B\_1 0 BDE\_B\_2 0 EGLKIHF\_G\_3 0 HIKJ\_H\_1 0 KLNM\_L\_3 0

ABEC\_B\_2 1 BDE\_D\_1 1 EGLKIHF\_H\_1 1 HIKJ\_H\_2 1 KLNM\_M\_1 1

ABEC\_B\_3 1 BDE\_D\_2 0 EGLKIHF\_H\_2 0 HIKJ\_I\_1 1 KLNM\_M\_2 0

ABEC\_B\_4 1 BDE\_E\_1 1 EGLKIHF\_H\_3 0 HIKJ\_I\_2 0 KLNM\_M\_3 0

ABEC\_C\_1 0 BDE\_E\_2 0 EGLKIHF\_I\_1 0 HIKJ\_J\_1 1 KLNM\_N\_1 1

ABEC\_C\_2 0 EGLKIHF\_E\_1 1 EGLKIHF\_I\_2 0 HIKJ\_J\_2 1 KLNM\_N\_2 1

ABEC\_C\_3 0 EGLKIHF\_E\_2 1 EGLKIHF\_I\_3 0 HIKJ\_K\_1 1 KLNM\_N\_3 1

ABEC\_C\_4 1 EGLKIHF\_E\_3 1 EGLKIHF\_K\_1 0 HIKJ\_K\_2 0

ABEC\_E\_1 1 EGLKIHF\_F\_1 1 EGLKIHF\_K\_2 1 KLNM\_K\_1 0

Appendix D: AMPL Output of running full Caldata network to completion

Total\_Cost = 37731000

adm [\*] :=

ABEC\_A\_1 1 ABEC[\_E\_2 0 EGLKIHF\_F\_2 0 EGLKIHF\_K\_3 0 KLNM\_K\_2 0

ABEC\_A\_2 1 ABEC\_E\_3 1 EGLKIHF\_F\_3 0 EGLKIHF\_L\_1 0 KLNM\_K\_3 1

ABEC\_A\_3 0 ABEC\_E\_4 1 EGLKIHF\_G\_1 1 EGLKIHF\_L\_2 0 KLNM\_L\_1 0

ABEC\_A\_4 1 BDE\_B\_1 1 EGLKIHF\_G\_2 0 EGLKIHF\_L\_3 1 KLNM\_L\_2 1

ABEC\_B\_1 0 BDE\_B\_2 0 EGLKIHF\_G\_3 0 HIKJ\_H\_1 0 KLNM\_L\_3 0

ABEC\_B\_2 1 BDE\_D\_1 1 EGLKIHF\_H\_1 1 HIKJ\_H\_2 1 KLNM\_M\_1 1

ABEC\_B\_3 1 BDE\_D\_2 0 EGLKIHF\_H\_2 0 HIKJ\_I\_1 1 KLNM\_M\_2 0

ABEC\_B\_4 1 BDE\_E\_1 1 EGLKIHF\_H\_3 0 HIKJ\_I\_2 0 KLNM\_M\_3 0

ABEC\_C\_1 0 BDE\_E\_2 0 EGLKIHF\_I\_1 0 HIKJ\_J\_1 1 KLNM\_N\_1 1

ABEC\_C\_2 0 EGLKIHF\_E\_1 1 EGLKIHF\_I\_2 0 HIKJ\_J\_2 1 KLNM\_N\_2 1

ABEC\_C\_3 1 EGLKIHF\_E\_2 1 EGLKIHF\_I\_3 0 HIKJ\_K\_1 1 KLNM\_N\_3 1

ABEC\_C\_4 0 EGLKIHF\_E\_3 1 EGLKIHF\_K\_1 0 HIKJ\_K\_2 0

ABEC\_E\_1 1 EGLKIHF\_F\_1 1 EGLKIHF\_K\_2 1 KLNM\_K\_1 1

33 ADMs

Appendix E: AMPL Output of running Caldata network split into 2 data files split at Hub E (excludes jump flows)

Top

Total\_Cost = 10921000

adm [\*] :=

ABEC\_A\_1 0 ABEC\_B\_1 0 ABEC\_C\_1 0 ABEC\_E\_1 0 BDE\_B\_1 1 BDE\_E\_1 0

ABEC\_A\_2 1 ABEC\_B\_2 1 ABEC\_C\_2 1 ABEC\_E\_2 0 BDE\_B\_2 0 BDE\_E\_2 0

ABEC\_A\_3 1 ABEC\_B\_3 1 ABEC\_C\_3 0 ABEC\_E\_3 1 BDE\_D\_1 1

ABEC\_A\_4 1 ABEC\_B\_4 1 ABEC\_C\_4 0 ABEC\_E\_4 0 BDE\_D\_2 0

10 ADMs

Bottom

Total\_Cost = 14837000

adm [\*] :=

EFHIKLG\_E\_1 0 EFHIKLG\_H\_1 1 EFHIKLG\_L\_1 0 HIKJ\_K\_1 1 KMNL\_M\_2 0

EFHIKLG\_E\_2 0 EFHIKLG\_H\_2 0 EFHIKLG\_L\_2 0 HIKJ\_K\_2 0 KMNL\_M\_3 1

EFHIKLG\_E\_3 1 EFHIKLG\_H\_3 0 EFHIKLG\_L\_3 0 KMNL\_K\_1 0 KMNL\_N\_1 0

EFHIKLG\_F\_1 1 EFHIKLG\_I\_1 0 HIKJ\_H\_1 1 KMNL\_K\_2 1 KMNL\_N\_2 1

EFHIKLG\_F\_2 0 EFHIKLG\_I\_2 0 HIKJ\_H\_2 0 KMNL\_K\_3 1 KMNL\_N\_3 1

EFHIKLG\_F\_3 0 EFHIKLG\_I\_3 0 HIKJ\_I\_1 1 KMNL\_L\_1 0

EFHIKLG\_G\_1 0 EFHIKLG\_K\_1 0 HIKJ\_I\_2 0 KMNL\_L\_2 1

EFHIKLG\_G\_2 0 EFHIKLG\_K\_2 0 HIKJ\_J\_1 1 KMNL\_L\_3 0

EFHIKLG\_G\_3 1 EFHIKLG\_K\_3 0 HIKJ\_J\_2 0 KMNL\_M\_1 0

14 ADMs

Appendix F: AMPL Output of running Caldata network split into 2 data files split at Hub E (includes jump flows)

Top

Total\_Cost = 14505000

adm [\*] :=

ABEC\_A\_1 1 ABEC\_B\_1 1 ABEC\_C\_1 0 ABEC\_E\_1 1 BDE\_B\_1 0 BDE\_E\_1 0

ABEC\_A\_2 1 ABEC\_B\_2 0 ABEC\_C\_2 0 ABEC\_E\_2 1 BDE\_B\_2 1 BDE\_E\_2 1

ABEC\_A\_3 0 ABEC\_B\_3 1 ABEC\_C\_3 1 ABEC\_E\_3 1 BDE\_D\_1 0

ABEC\_A\_4 1 ABEC\_B\_4 1 ABEC\_C\_4 0 ABEC\_E\_4 0 BDE\_D\_2 1

13 ADMs

Bottom

Total\_Cost = 22814000

adm [\*] :=

EFHIKLG\_E\_1 1 EFHIKLG\_H\_1 1 EFHIKLG\_L\_1 0 HIKJ\_K\_1 0 KMNL\_M\_2 0

EFHIKLG\_E\_2 1 EFHIKLG\_H\_2 0 EFHIKLG\_L\_2 1 HIKJ\_K\_2 1 KMNL\_M\_3 0

EFHIKLG\_E\_3 1 EFHIKLG\_H\_3 0 EFHIKLG\_L\_3 0 KMNL\_K\_1 1 KMNL\_N\_1 1

EFHIKLG\_F\_1 1 EFHIKLG\_I\_1 0 HIKJ\_H\_1 1 KMNL\_K\_2 0 KMNL\_N\_2 1

EFHIKLG\_F\_2 0 EFHIKLG\_I\_2 0 HIKJ\_H\_2 0 KMNL\_K\_3 1 KMNL\_N\_3 1

EFHIKLG\_F\_3 0 EFHIKLG\_I\_3 0 HIKJ\_I\_1 0 KMNL\_L\_1 0

EFHIKLG\_G\_1 1 EFHIKLG\_K\_1 0 HIKJ\_I\_2 1 KMNL\_L\_2 1

EFHIKLG\_G\_2 0 EFHIKLG\_K\_2 0 HIKJ\_J\_1 1 KMNL\_L\_3 0

EFHIKLG\_G\_3 0 EFHIKLG\_K\_3 1 HIKJ\_J\_2 1 KMNL\_M\_1 1

20 ADMs

Appendix G: AMPL Output of running Barry network Min Cost Flow Problem

Total\_Cost = 11791100

adm [\*] :=

ABLNIKMQHD\_A\_1 1 ABLNIKMQHD\_M\_1 1 IPTUJFK\_T\_2 1 MEGRCOSQ\_M\_6 1

ABLNIKMQHD\_A\_2 1 ABLNIKMQHD\_M\_2 1 IPTUJFK\_T\_3 1 MEGRCOSQ\_O\_1 1

ABLNIKMQHD\_A\_3 1 ABLNIKMQHD\_M\_3 1 IPTUJFK\_U\_1 1 MEGRCOSQ\_O\_2 1

ABLNIKMQHD\_A\_4 1 ABLNIKMQHD\_M\_4 1 IPTUJFK\_U\_2 1 MEGRCOSQ\_O\_3 1

ABLNIKMQHD\_B\_1 1 ABLNIKMQHD\_N\_1 1 IPTUJFK\_U\_3 1 MEGRCOSQ\_O\_4 1

ABLNIKMQHD\_B\_2 1 ABLNIKMQHD\_N\_2 1 MEGRCOSQ\_C\_1 1 MEGRCOSQ\_O\_5 1

ABLNIKMQHD\_B\_3 1 ABLNIKMQHD\_N\_3 1 MEGRCOSQ\_C\_2 1 MEGRCOSQ\_O\_6 1

ABLNIKMQHD\_B\_4 1 ABLNIKMQHD\_N\_4 1 MEGRCOSQ\_C\_3 1 MEGRCOSQ\_Q\_1 1

ABLNIKMQHD\_D\_1 1 ABLNIKMQHD\_Q\_1 1 MEGRCOSQ\_C\_4 1 MEGRCOSQ\_Q\_2 1

ABLNIKMQHD\_D\_2 1 ABLNIKMQHD\_Q\_2 1 MEGRCOSQ\_C\_5 1 MEGRCOSQ\_Q\_3 1

ABLNIKMQHD\_D\_3 1 ABLNIKMQHD\_Q\_3 1 MEGRCOSQ\_C\_6 1 MEGRCOSQ\_Q\_4 1

ABLNIKMQHD\_D\_4 1 ABLNIKMQHD\_Q\_4 1 MEGRCOSQ\_E\_1 1 MEGRCOSQ\_Q\_5 1

ABLNIKMQHD\_H\_1 1 IPTUJFK\_F\_1 1 MEGRCOSQ\_E\_2 1 MEGRCOSQ\_Q\_6 1

ABLNIKMQHD\_H\_2 1 IPTUJFK\_F\_2 1 MEGRCOSQ\_E\_3 1 MEGRCOSQ\_R\_1 1

ABLNIKMQHD\_H\_3 1 IPTUJFK\_F\_3 1 MEGRCOSQ\_E\_4 1 MEGRCOSQ\_R\_2 1

ABLNIKMQHD\_H\_4 1 IPTUJFK\_I\_1 1 MEGRCOSQ\_E\_5 1 MEGRCOSQ\_R\_3 1

ABLNIKMQHD\_I\_1 1 IPTUJFK\_I\_2 1 MEGRCOSQ\_E\_6 1 MEGRCOSQ\_R\_4 1

ABLNIKMQHD\_I\_2 1 IPTUJFK\_I\_3 1 MEGRCOSQ\_G\_1 1 MEGRCOSQ\_R\_5 1

ABLNIKMQHD\_I\_3 1 IPTUJFK\_J\_1 1 MEGRCOSQ\_G\_2 1 MEGRCOSQ\_R\_6 1

ABLNIKMQHD\_I\_4 1 IPTUJFK\_J\_2 1 MEGRCOSQ\_G\_3 1 MEGRCOSQ\_S\_1 1

ABLNIKMQHD\_K\_1 1 IPTUJFK\_J\_3 1 MEGRCOSQ\_G\_4 1 MEGRCOSQ\_S\_2 1

ABLNIKMQHD\_K\_2 1 IPTUJFK\_K\_1 1 MEGRCOSQ\_G\_5 1 MEGRCOSQ\_S\_3 1

ABLNIKMQHD\_K\_3 1 IPTUJFK\_K\_2 1 MEGRCOSQ\_G\_6 1 MEGRCOSQ\_S\_4 1

ABLNIKMQHD\_K\_4 1 IPTUJFK\_K\_3 1 MEGRCOSQ\_M\_1 1 MEGRCOSQ\_S\_5 1

ABLNIKMQHD\_L\_1 1 IPTUJFK\_P\_1 1 MEGRCOSQ\_M\_2 1 MEGRCOSQ\_S\_6 1

ABLNIKMQHD\_L\_2 1 IPTUJFK\_P\_2 1 MEGRCOSQ\_M\_3 1

ABLNIKMQHD\_L\_3 1 IPTUJFK\_P\_3 1 MEGRCOSQ\_M\_4 1

ABLNIKMQHD\_L\_4 1 IPTUJFK\_T\_1 1 MEGRCOSQ\_M\_5 1

109 ADMs

Appendix H: AMPL Output of running full Barry network with binary constraint relaxed

Total\_Cost = 24267800

adm [\*] :=

ABLNIKMQHD\_A\_1 0.271823 IPTUJFK\_T\_1 0.0416667

ABLNIKMQHD\_A\_2 0.116445 IPTUJFK\_T\_2 0.125

ABLNIKMQHD\_A\_3 0.109649 IPTUJFK\_T\_3 0.145833

ABLNIKMQHD\_A\_4 0.189583 IPTUJFK\_U\_1 0

ABLNIKMQHD\_B\_1 0.271823 IPTUJFK\_U\_2 0

ABLNIKMQHD\_B\_2 0.116445 IPTUJFK\_U\_3 0.09375

ABLNIKMQHD\_B\_3 0.109649 MEGRCOSQ\_C\_1 0

ABLNIKMQHD\_B\_4 0.189583 MEGRCOSQ\_C\_2 0.0104167

ABLNIKMQHD\_D\_1 0.107239 MEGRCOSQ\_C\_3 0

ABLNIKMQHD\_D\_2 0.116445 MEGRCOSQ\_C\_4 0.114583

ABLNIKMQHD\_D\_3 0.109649 MEGRCOSQ\_C\_5 0.03125

ABLNIKMQHD\_D\_4 0.0208333 MEGRCOSQ\_C\_6 0.0625

ABLNIKMQHD\_H\_1 0 MEGRCOSQ\_E\_1 0.0115108

ABLNIKMQHD\_H\_2 0.0479771 MEGRCOSQ\_E\_2 0.25

ABLNIKMQHD\_H\_3 0 MEGRCOSQ\_E\_3 0

ABLNIKMQHD\_H\_4 0.0561896 MEGRCOSQ\_E\_4 0.0137137

ABLNIKMQHD\_I\_1 0.0575242 MEGRCOSQ\_E\_5 0.0372755

ABLNIKMQHD\_I\_2 0.0276902 MEGRCOSQ\_E\_6 0.0208333

ABLNIKMQHD\_I\_3 0.0370646 MEGRCOSQ\_G\_1 0.25

ABLNIKMQHD\_I\_4 0.065221 MEGRCOSQ\_G\_2 0.25

ABLNIKMQHD\_K\_1 0.0285623 MEGRCOSQ\_G\_3 0.25

ABLNIKMQHD\_K\_2 0.0208333 MEGRCOSQ\_G\_4 0.385417

ABLNIKMQHD\_K\_3 0.0183676 MEGRCOSQ\_G\_5 0.302987

ABLNIKMQHD\_K\_4 0.0364034 MEGRCOSQ\_G\_6 0.405346

ABLNIKMQHD\_L\_1 0.0104167 MEGRCOSQ\_M\_1 0.0115108

ABLNIKMQHD\_L\_2 0.0208333 MEGRCOSQ\_M\_2 0.0363085

ABLNIKMQHD\_L\_3 0 MEGRCOSQ\_M\_3 0.0151902

ABLNIKMQHD\_L\_4 0.0729167 MEGRCOSQ\_M\_4 0.00685687

ABLNIKMQHD\_M\_1 0.0363085 MEGRCOSQ\_M\_5 0.0131673

ABLNIKMQHD\_M\_2 0.0208333 MEGRCOSQ\_M\_6 0.0315497

ABLNIKMQHD\_M\_3 0.0315497 MEGRCOSQ\_O\_1 0.25

ABLNIKMQHD\_M\_4 0.0363085 MEGRCOSQ\_O\_2 0.25

ABLNIKMQHD\_N\_1 0.0952055 MEGRCOSQ\_O\_3 0.25

ABLNIKMQHD\_N\_2 0.0276902 MEGRCOSQ\_O\_4 0.173179

ABLNIKMQHD\_N\_3 0.0370646 MEGRCOSQ\_O\_5 0.165763

ABLNIKMQHD\_N\_4 0.162956 MEGRCOSQ\_O\_6 0.140224

ABLNIKMQHD\_Q\_1 0.0125 MEGRCOSQ\_Q\_1 0.0125

ABLNIKMQHD\_Q\_2 0.0125 MEGRCOSQ\_Q\_2 0.0125

ABLNIKMQHD\_Q\_3 0.0125 MEGRCOSQ\_Q\_3 0.0125

ABLNIKMQHD\_Q\_4 0.0125 MEGRCOSQ\_Q\_4 0.0125

IPTUJFK\_F\_1 0.114583 MEGRCOSQ\_Q\_5 0.0125

IPTUJFK\_F\_2 0.224698 MEGRCOSQ\_Q\_6 0.0125

IPTUJFK\_F\_3 0.296136 MEGRCOSQ\_R\_1 0.25

IPTUJFK\_I\_1 0.0416667 MEGRCOSQ\_R\_2 0.25

IPTUJFK\_I\_2 0.125 MEGRCOSQ\_R\_3 0.25

IPTUJFK\_I\_3 0.15625 MEGRCOSQ\_R\_4 0.385417

IPTUJFK\_J\_1 0.114583 MEGRCOSQ\_R\_5 0.302987

IPTUJFK\_J\_2 0.224698 MEGRCOSQ\_R\_6 0.405346

IPTUJFK\_J\_3 0.296136 MEGRCOSQ\_S\_1 0.197917

IPTUJFK\_K\_1 0.0416667 MEGRCOSQ\_S\_2 0.25

IPTUJFK\_K\_2 0.0364034 MEGRCOSQ\_S\_3 0.25

IPTUJFK\_K\_3 0.0677632 MEGRCOSQ\_S\_4 0.173179

IPTUJFK\_P\_1 0.0416667 MEGRCOSQ\_S\_5 0.165763

IPTUJFK\_P\_2 0.125 MEGRCOSQ\_S\_6 0.140224

IPTUJFK\_P\_3 0.15625

Appendix I: AMPL Output of running Barry split 3 ways with flow through networks (excludes jump flows)

Top

Total\_Cost = 14131700

adm [\*] :=

ABLNIKMQHD\_A\_1 1 ABLNIKMQHD\_D\_3 0 ABLNIKMQHD\_K\_1 1 ABLNIKMQHD\_M\_3 0

ABLNIKMQHD\_A\_2 1 ABLNIKMQHD\_D\_4 1 ABLNIKMQHD\_K\_2 0 ABLNIKMQHD\_M\_4 0

ABLNIKMQHD\_A\_3 0 ABLNIKMQHD\_H\_1 0 ABLNIKMQHD\_K\_3 0 ABLNIKMQHD\_N\_1 1

ABLNIKMQHD\_A\_4 1 ABLNIKMQHD\_H\_2 0 ABLNIKMQHD\_K\_4 0 ABLNIKMQHD\_N\_2 0

ABLNIKMQHD\_B\_1 0 ABLNIKMQHD\_H\_3 0 ABLNIKMQHD\_L\_1 1 ABLNIKMQHD\_N\_3 0

ABLNIKMQHD\_B\_2 1 ABLNIKMQHD\_H\_4 1 ABLNIKMQHD\_L\_2 0 ABLNIKMQHD\_N\_4 0

ABLNIKMQHD\_B\_3 0 ABLNIKMQHD\_I\_1 1 ABLNIKMQHD\_L\_3 0 ABLNIKMQHD\_Q\_1 0

ABLNIKMQHD\_B\_4 0 ABLNIKMQHD\_I\_2 0 ABLNIKMQHD\_L\_4 0 ABLNIKMQHD\_Q\_2 1

ABLNIKMQHD\_D\_1 0 ABLNIKMQHD\_I\_3 0 ABLNIKMQHD\_M\_1 1 ABLNIKMQHD\_Q\_3 0

ABLNIKMQHD\_D\_2 0 ABLNIKMQHD\_I\_4 0 ABLNIKMQHD\_M\_2 0 ABLNIKMQHD\_Q\_4 0

12 ADMs

Right

Total\_Cost = 10658000

adm [\*] :=

IPTUJFK\_F\_1 0 IPTUJFK\_I\_3 1 IPTUJFK\_K\_2 1 IPTUJFK\_T\_1 0 IPTUJFK\_U\_3 0

IPTUJFK\_F\_2 0 IPTUJFK\_J\_1 0 IPTUJFK\_K\_3 0 IPTUJFK\_T\_2 1

IPTUJFK\_F\_3 1 IPTUJFK\_J\_2 1 IPTUJFK\_P\_1 0 IPTUJFK\_T\_3 0

IPTUJFK\_I\_1 0 IPTUJFK\_J\_3 1 IPTUJFK\_P\_2 1 IPTUJFK\_U\_1 0

IPTUJFK\_I\_2 1 IPTUJFK\_K\_1 0 IPTUJFK\_P\_3 0 IPTUJFK\_U\_2 1

9 ADMs

Left

Total\_Cost = 19728800

adm [\*] :=

MEGRCOSQ\_C\_1 0 MEGRCOSQ\_G\_1 1 MEGRCOSQ\_O\_1 1 MEGRCOSQ\_R\_1 0

MEGRCOSQ\_C\_2 0 MEGRCOSQ\_G\_2 1 MEGRCOSQ\_O\_2 1 MEGRCOSQ\_R\_2 0

MEGRCOSQ\_C\_3 0 MEGRCOSQ\_G\_3 1 MEGRCOSQ\_O\_3 0 MEGRCOSQ\_R\_3 1

MEGRCOSQ\_C\_4 1 MEGRCOSQ\_G\_4 1 MEGRCOSQ\_O\_4 1 MEGRCOSQ\_R\_4 1

MEGRCOSQ\_C\_5 0 MEGRCOSQ\_G\_5 1 MEGRCOSQ\_O\_5 0 MEGRCOSQ\_R\_5 1

MEGRCOSQ\_C\_6 0 MEGRCOSQ\_G\_6 0 MEGRCOSQ\_O\_6 0 MEGRCOSQ\_R\_6 0

MEGRCOSQ\_E\_1 0 MEGRCOSQ\_M\_1 1 MEGRCOSQ\_Q\_1 0 MEGRCOSQ\_S\_1 1

MEGRCOSQ\_E\_2 0 MEGRCOSQ\_M\_2 0 MEGRCOSQ\_Q\_2 0 MEGRCOSQ\_S\_2 0

MEGRCOSQ\_E\_3 0 MEGRCOSQ\_M\_3 0 MEGRCOSQ\_Q\_3 0 MEGRCOSQ\_S\_3 0

MEGRCOSQ\_E\_4 0 MEGRCOSQ\_M\_4 0 MEGRCOSQ\_Q\_4 0 MEGRCOSQ\_S\_4 1

MEGRCOSQ\_E\_5 1 MEGRCOSQ\_M\_5 0 MEGRCOSQ\_Q\_5 0 MEGRCOSQ\_S\_5 0

MEGRCOSQ\_E\_6 0 MEGRCOSQ\_M\_6 0 MEGRCOSQ\_Q\_6 0 MEGRCOSQ\_S\_6 0

16 ADMs

Appendix J: AMPL Output of running Barry split 3 ways with flow through networks (includes jump flows)

Top

Total\_Cost = 20931000

adm [\*] :=

ABLNIKMQHD\_A\_1 1 ABLNIKMQHD\_D\_3 1 ABLNIKMQHD\_K\_1 1 ABLNIKMQHD\_M\_3 0

ABLNIKMQHD\_A\_2 1 ABLNIKMQHD\_D\_4 0 ABLNIKMQHD\_K\_2 1 ABLNIKMQHD\_M\_4 1

ABLNIKMQHD\_A\_3 1 ABLNIKMQHD\_H\_1 0 ABLNIKMQHD\_K\_3 0 ABLNIKMQHD\_N\_1 0

ABLNIKMQHD\_A\_4 1 ABLNIKMQHD\_H\_2 0 ABLNIKMQHD\_K\_4 0 ABLNIKMQHD\_N\_2 1

ABLNIKMQHD\_B\_1 1 ABLNIKMQHD\_H\_3 1 ABLNIKMQHD\_L\_1 0 ABLNIKMQHD\_N\_3 0

ABLNIKMQHD\_B\_2 0 ABLNIKMQHD\_H\_4 0 ABLNIKMQHD\_L\_2 1 ABLNIKMQHD\_N\_4 0

ABLNIKMQHD\_B\_3 0 ABLNIKMQHD\_I\_1 0 ABLNIKMQHD\_L\_3 0 ABLNIKMQHD\_Q\_1 0

ABLNIKMQHD\_B\_4 0 ABLNIKMQHD\_I\_2 1 ABLNIKMQHD\_L\_4 0 ABLNIKMQHD\_Q\_2 1

ABLNIKMQHD\_D\_1 0 ABLNIKMQHD\_I\_3 0 ABLNIKMQHD\_M\_1 0 ABLNIKMQHD\_Q\_3 1

ABLNIKMQHD\_D\_2 0 ABLNIKMQHD\_I\_4 1 ABLNIKMQHD\_M\_2 1 ABLNIKMQHD\_Q\_4 0

17 ADMs

Right:

Total\_Cost = 13259600

adm [\*] :=

IPTUJFK\_F\_1 1 IPTUJFK\_I\_3 1 IPTUJFK\_K\_2 1 IPTUJFK\_T\_1 0 IPTUJFK\_U\_3 0

IPTUJFK\_F\_2 1 IPTUJFK\_J\_1 1 IPTUJFK\_K\_3 0 IPTUJFK\_T\_2 0

IPTUJFK\_F\_3 0 IPTUJFK\_J\_2 1 IPTUJFK\_P\_1 0 IPTUJFK\_T\_3 1

IPTUJFK\_I\_1 1 IPTUJFK\_J\_3 1 IPTUJFK\_P\_2 0 IPTUJFK\_U\_1 1

IPTUJFK\_I\_2 0 IPTUJFK\_K\_1 0 IPTUJFK\_P\_3 1 IPTUJFK\_U\_2 0

11 ADMs

Left:

Total\_Cost = 25334700

adm [\*] :=

MEGRCOSQ\_C\_1 0 MEGRCOSQ\_G\_1 1 MEGRCOSQ\_O\_1 1 MEGRCOSQ\_R\_1 0

MEGRCOSQ\_C\_2 1 MEGRCOSQ\_G\_2 1 MEGRCOSQ\_O\_2 1 MEGRCOSQ\_R\_2 0

MEGRCOSQ\_C\_3 0 MEGRCOSQ\_G\_3 1 MEGRCOSQ\_O\_3 0 MEGRCOSQ\_R\_3 1

MEGRCOSQ\_C\_4 0 MEGRCOSQ\_G\_4 0 MEGRCOSQ\_O\_4 1 MEGRCOSQ\_R\_4 1

MEGRCOSQ\_C\_5 0 MEGRCOSQ\_G\_5 1 MEGRCOSQ\_O\_5 0 MEGRCOSQ\_R\_5 1

MEGRCOSQ\_C\_6 0 MEGRCOSQ\_G\_6 1 MEGRCOSQ\_O\_6 1 MEGRCOSQ\_R\_6 0

MEGRCOSQ\_E\_1 0 MEGRCOSQ\_M\_1 1 MEGRCOSQ\_Q\_1 0 MEGRCOSQ\_S\_1 0

MEGRCOSQ\_E\_2 1 MEGRCOSQ\_M\_2 1 MEGRCOSQ\_Q\_2 1 MEGRCOSQ\_S\_2 1

MEGRCOSQ\_E\_3 0 MEGRCOSQ\_M\_3 0 MEGRCOSQ\_Q\_3 0 MEGRCOSQ\_S\_3 0

MEGRCOSQ\_E\_4 0 MEGRCOSQ\_M\_4 0 MEGRCOSQ\_Q\_4 0 MEGRCOSQ\_S\_4 1

MEGRCOSQ\_E\_5 0 MEGRCOSQ\_M\_5 0 MEGRCOSQ\_Q\_5 0 MEGRCOSQ\_S\_5 0

MEGRCOSQ\_E\_6 0 MEGRCOSQ\_M\_6 0 MEGRCOSQ\_Q\_6 1 MEGRCOSQ\_S\_6 0

20 ADMs

Appendix K: Excel table showing sum of flows and calculation of minimum ADMs for Caldata network.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Origin | Destination | Demand | Through | Origin | Destination | Demand |
| A | B | 38,000 |  | B | A | 42,000 |
| A | D | 7,000 | E or B | K | A | 11,000 |
| A | N | 27,000 | E,L or E,K | D | A | 12,000 |
| A | E | 5,000 |  | C | A | 1,000 |
| A | J | 1,000 | E,H or E,K | A | B | 38,000 |
| B | K | 13,000 | E | B | C | 1,000 |
| B | D | 19,000 |  | D | C | 1,000 |
| B | C | 1,000 |  | A | D | 7,000 |
| B | A | 42,000 |  | B | D | 19,000 |
| B | N | 31,000 | E,L or E,K | B | E | 7,000 |
| B | E | 7,000 |  | A | E | 5,000 |
| B | F | 6,000 | E | B | F | 6,000 |
| B | J | 9,000 | E,H or E,K | E | G | 3,000 |
| B | H | 2,000 | E | B | H | 2,000 |
| C | A | 1,000 |  | K | H | 6,000 |
| D | C | 1,000 | B or E | J | H | 4,000 |
| D | A | 12,000 | B or E | K | I | 1,000 |
| D | N | 1,000 | E,K or E,L | B | J | 9,000 |
| D | J | 2,000 | E,H or E,K | K | J | 14,000 |
| E | G | 3,000 |  | D | J | 2,000 |
| F | J | 2,000 | H or K | M | J | 1,000 |
| J | H | 4,000 |  | A | J | 1,000 |
| J | L | 2,000 | K or H | N | J | 20,000 |
| K | I | 1,000 |  | F | J | 2,000 |
| K | M | 2,000 |  | B | K | 13,000 |
| K | A | 11,000 | E | K | L | 6,000 |
| K | N | 32,000 |  | N | L | 11,000 |
| K | J | 14,000 |  | J | L | 2,000 |
| K | H | 6,000 |  | K | M | 2,000 |
| K | L | 6,000 |  | B | N | 31,000 |
| M | J | 1,000 | K | K | N | 32,000 |
| N | J | 20,000 | K | D | N | 1,000 |
| N | L | 11,000 |  | A | N | 27,000 |
|  |  | 123,000 |  |  |  |  |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Node | Total Flow | Individual flow | ADMS | Upper integer | Jump Flows | Nodes | Final ADMs |
| A | 144,000 | 144,000 | 3 | 3 |  | A | 3 |
| B | 192,000 | 168,000 | 4 | 4 | 24000 | B | 4 |
| C | 3,000 | 3,000 | 0.0625 | 1 |  | C | 1 |
| D | 42,000 | 42,000 | 0.875 | 1 |  | D | 1 |
| E | 237,000 | 15,000 | 4.9375 | 5 | 222000 | E | 7 |
| F | 8,000 | 8,000 | 0.1667 | 1 |  | F | 1 |
| G | 3,000 | 3,000 | 0.0625 | 1 |  | G | 1 |
| H | 44,000 | 12,000 | 0.9167 | 1 | 32000 | H | 2 |
| I | 1,000 | 1,000 | 0.02083 | 1 |  | I | 1 |
| J | 55,000 | 55,000 | 1.14583 | 2 |  | J | 2 |
| K | 239,000 | 85,000 | 4.97917 | 5 | 154000 | K | 4 |
| L | 25,000 | 19,000 | 0.52083 | 1 | 6000 | L | 2 |
| M | 3,000 | 3,000 | 0.0625 | 1 |  | M | 1 |
| N | 122,000 | 122,000 | 2.54167 | 3 |  | N | 3 |
| Total | 1,118,000 | 680,000 |  |  |  |  |  |
|  |  |  |  | 30 | 438000 |  | 33 |

Appendix L: Excel table showing sum of flows and calculation of minimum ADMs for Caldata network.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Origin | Destination | Demand | Through | Origin | Destination | Demand |
| A | B | 66,000 |  | A | B | 66,000 |
| A | C | 1,000 | Q/M | A | C | 1,000 |
| A | D | 34,000 |  | A | D | 34,000 |
| A | E | 2,000 | Q/M | A | E | 2,000 |
| A | F | 2,000 | I/K | A | F | 2,000 |
| A | G | 23,000 | Q/M | T | F | 2,000 |
| A | H | 10,000 |  | B | F | 1,000 |
| A | I | 16,000 |  | A | G | 23,000 |
| A | J | 13,000 | I/K | B | G | 3,000 |
| A | K | 6,000 |  | C | G | 14,000 |
| A | L | 9,000 |  | E | G | 32,000 |
| A | M | 23,000 |  | F | G | 6,000 |
| A | N | 17,000 |  | A | H | 10,000 |
| A | O | 57,000 | Q/M | D | H | 2,000 |
| A | P | 9,000 | I/K | A | I | 16,000 |
| A | Q | 12,000 |  | T | I | 3,000 |
| A | R | 1,000 | Q/M | B | I | 8,000 |
| A | S | 21,000 | Q/M | C | I | 1,000 |
| T | F | 2,000 |  | E | I | 8,000 |
| T | I | 3,000 |  | F | I | 19,000 |
| T | J | 1,000 |  | G | I | 13,000 |
| T | P | 30,000 |  | A | J | 13,000 |
| B | F | 1,000 | I/K | T | J | 1,000 |
| B | G | 3,000 | Q/M | B | J | 3,000 |
| B | I | 8,000 |  | E | J | 8,000 |
| B | J | 3,000 | I/K | F | J | 61,000 |
| B | K | 2,000 |  | G | J | 23,000 |
| B | L | 2,000 |  | I | J | 32,000 |
| B | N | 1,000 |  | A | K | 6,000 |
| B | O | 1,000 | Q/M | B | K | 2,000 |
| B | P | 2,000 | I/K | C | K | 1,000 |
| B | S | 1,000 | Q/M | E | K | 8,000 |
| C | G | 14,000 |  | F | K | 10,000 |
| C | I | 1,000 | Q/M | G | K | 4,000 |
| C | K | 1,000 | Q/M | I | K | 20,000 |
| C | O | 21,000 |  | J | K | 24,000 |
| C | R | 3,000 |  | A | L | 9,000 |
| C | S | 3,000 |  | B | L | 2,000 |
| D | H | 2,000 |  | I | L | 1,000 |
| E | G | 32,000 |  | A | M | 23,000 |
| E | I | 8,000 | Q/M | E | M | 2,000 |
| E | J | 8,000 | Q/M & I/K | G | M | 17,000 |
| E | K | 8,000 | Q/M | H | M | 1,000 |
| E | M | 2,000 |  | I | M | 10,000 |
| E | R | 1,000 |  | J | M | 8,000 |
| F | G | 6,000 | I/K & Q/M | K | M | 2,000 |
| F | I | 19,000 |  | A | N | 17,000 |
| F | J | 61,000 |  | B | N | 1,000 |
| F | K | 10,000 |  | I | N | 31,000 |
| F | P | 2,000 |  | J | N | 3,000 |
| F | S | 1,000 | I/K & Q/M | K | N | 2,000 |
| G | I | 13,000 | Q/M | L | N | 10,000 |
| G | J | 23,000 | Q/M & I/K | A | O | 57,000 |
| G | K | 4,000 | Q/M | B | O | 1,000 |
| G | M | 17,000 |  | C | O | 21,000 |
| G | O | 118,000 |  | G | O | 118,000 |
| G | P | 6,000 | Q/M & I/K | I | O | 18,000 |
| G | R | 177,000 |  | J | O | 16,000 |
| G | S | 15,000 |  | K | O | 10,000 |
| H | M | 1,000 |  | M | O | 4,000 |
| I | J | 32,000 |  | N | O | 1,000 |
| I | K | 20,000 |  | A | P | 9,000 |
| I | L | 1,000 |  | T | P | 30,000 |
| I | M | 10,000 |  | B | P | 2,000 |
| I | N | 31,000 |  | F | P | 2,000 |
| I | O | 18,000 | Q/M | G | P | 6,000 |
| I | P | 31,000 |  | I | P | 31,000 |
| I | R | 1,000 | Q/M | J | P | 11,000 |
| J | K | 24,000 |  | K | P | 2,000 |
| J | M | 8,000 | I/K | M | P | 1,000 |
| J | N | 3,000 | I/K | O | P | 9,000 |
| J | O | 16,000 | I/K & Q/M | A | Q | 12,000 |
| J | P | 11,000 |  | A | R | 1,000 |
| J | U | 9,000 |  | C | R | 3,000 |
| J | R | 1,000 | I/K & Q/M | E | R | 1,000 |
| K | M | 2,000 |  | G | R | 177,000 |
| K | N | 2,000 |  | I | R | 1,000 |
| K | O | 10,000 | Q/M | J | R | 1,000 |
| K | P | 2,000 |  | K | R | 2,000 |
| K | R | 2,000 | Q/M | O | R | 23,000 |
| L | N | 10,000 |  | A | S | 21,000 |
| M | O | 4,000 |  | B | S | 1,000 |
| M | P | 1,000 | K/I | C | S | 3,000 |
| M | S | 2,000 |  | F | S | 1,000 |
| N | O | 1,000 | Q/M | G | S | 15,000 |
| O | P | 9,000 | Q/M & K/I | M | S | 2,000 |
| O | R | 23,000 |  | O | S | 113,000 |
| O | S | 113,000 |  | R | S | 4,000 |
| R | S | 4,000 |  | J | U | 9,000 |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  | 1,360,000 |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Node | TOTAL FLOW | MIN ADMS | Upper integer | Jump flows | adms after jump |
| A | 322,000 | 3.3541667 | 4 |  | 4 |
| B | 90,000 | 0.9375 | 1 |  | 1 |
| C | 44,000 | 0.4583333 | 1 |  | 1 |
| D | 36,000 | 0.375 | 1 |  | 1 |
| E | 61,000 | 0.6354167 | 1 |  | 1 |
| F | 104,000 | 1.0833333 | 2 |  | 2 |
| G | 451,000 | 4.6979167 | 5 |  | 5 |
| H | 13,000 | 0.135417 | 1 |  | 1 |
| I | 212,000 | 2.203333 | 3 | 56000 | 3 |
| J | 213,000 | 2.21875 | 3 |  | 3 |
| K | 93,000 | 0.96875 | 1 | 56000 | 3 |
| L | 22,000 | 0.229167 | 1 |  | 1 |
| M | 70,000 | 0.729167 | 1 | 142000 | 4 |
| N | 65,000 | 0.677083 | 1 |  | 1 |
| O | 391,000 | 4.072967 | 5 |  | 5 |
| P | 103,000 | 1.072917 | 2 |  | 2 |
| Q | 12,000 | 0.125 | 1 | 105000 | 3 |
| R | 213,000 | 2.21875 | 3 |  | 3 |
| S | 160,000 | 1.66667 | 2 |  | 2 |
| T | 36,000 | 0.375 | 1 |  | 1 |
| U | 9,000 | 0.09375 | 1 |  | 1 |
|  | 2,720,000 |  | 41 |  | 48 |