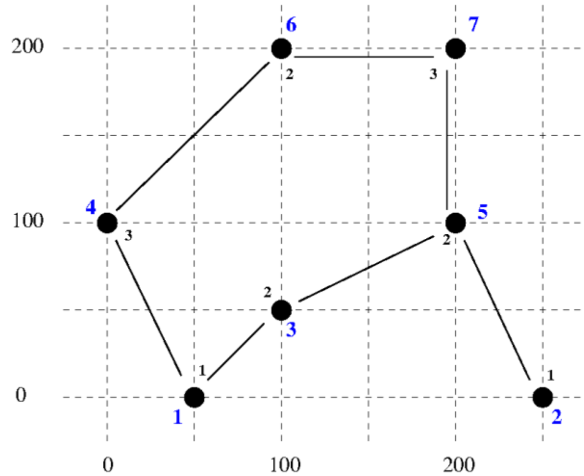
IEMS 313
Spring 2016
Project Phase I
Due Wednesday, May 11, before midnight.

NOTE: All project files MUST be submitted electronically. Please combine all submitted files into a single zip (or similar) file.

This project must be done in groups of ***three or four*** *people as coordinated with the TA.* ***You should not discuss your work with students outside your project group, including students not taking this course.*** *However, you may do whatever research you feel necessary to understand and approach the problem. This includes any online resources as well as course materials, instructor and TA.*

This project deals with the design of a railroad network. SmallRail currently operates a network depicted in this graph. The coordinates a given in miles.



This network has 7 stations (numbered in blue colors) that are connected with tracks (black lines). We have the following restrictions:

- *On each track only up to 10 shipment units can be transported.* If more goods need to transported, a new track needs to be built.
- *On each track, traffic can only go in one direction.* If goods need to be shipped in both directions, a new track needs to be built, so that we have one for each direction.
- Stations need to reorganize the goods on different trains. This is done in reloading buildings. *One reloading building can handle up to 5* incoming *shipping units.* In the picture above, the number of existing reloading buildings for each station is given by the black number next to the station.

In table form, we write this network as this:

- Set of stations

Station	x-coordinate	y-coordinate	# existing reloading buildings
1	50	0	1
2	250	0	1
3	100	50	2
4	0	100	3
5	200	100	2
6	100	200	2
7	200	200	3

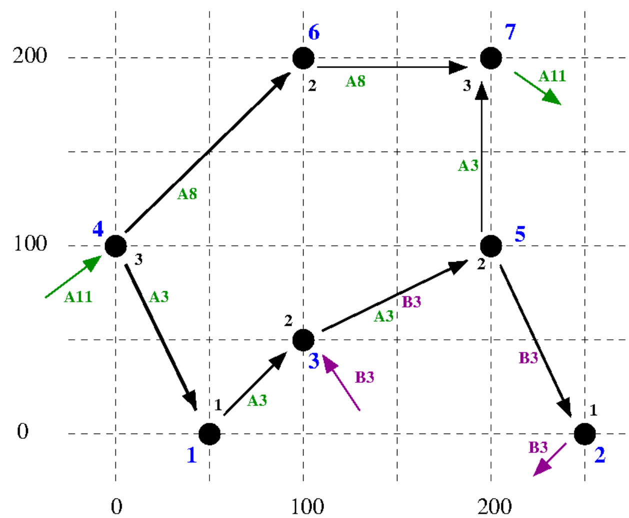
- Set of tracks

Station	Station	# existing tracks
1	3	1
1	4	1
2	5	1
3	5	1
4	6	1
5	7	1
6	7	1

Currently, SmallRail is operating two shipments, given in this table:

Shipment	Origin	Destination	Total volume	Path	Path volume
A	4	7	11	4-6-7	8
				4-1-3-5-7	3
B	3	2	3	3-5-2	3

- Shipments are happening on an ongoing basis, so we can understand them as a constant stream of goods that go come one particular station to another. For example, Shipment A is transported from station 4 to station 7, and it has a total volume of 11 units of goods per day.
- SmallRail needs to determine for each shipment how it is transported from origin to destination. Their current routing plan is given in the above table, and depicted in the following picture:



For example, there are 11 units of goods that need to be transported from station 4 to station 7 (shipment A). At station 4, eight units are sent from station 4 to station 6 (and then further from 6 to 7), and three units are shipped from station 4 to station 1 (and then via stations 3 and 5 to destination 7). Similarly, shipment B of three units of goods is going from 3 via 5 to 2. Note that the two shipments can share the track between 2 and 5 since they are both going into the same direction, and their combined volume of six is less than the per-track limit 10. (Suppose, the B shipment consisted of 9 units, then we would need an additional track between stations 3 and 5 to handle the total of 9+2=12 units from shipments A and B combined).
Also note that the number of reloading buildings is sufficient at all stations for the above plan. For example, the total amount of incoming goods at station 3 is three units from shipment A and three units from shipment B, amounting to a total of 6 units of incoming goods. This can be handled by the two reloading buildings at that station. (Again, suppose that shipment B consisted of nine units. Then we would require at least 3 reloading buildings at stations 3 and 5.)

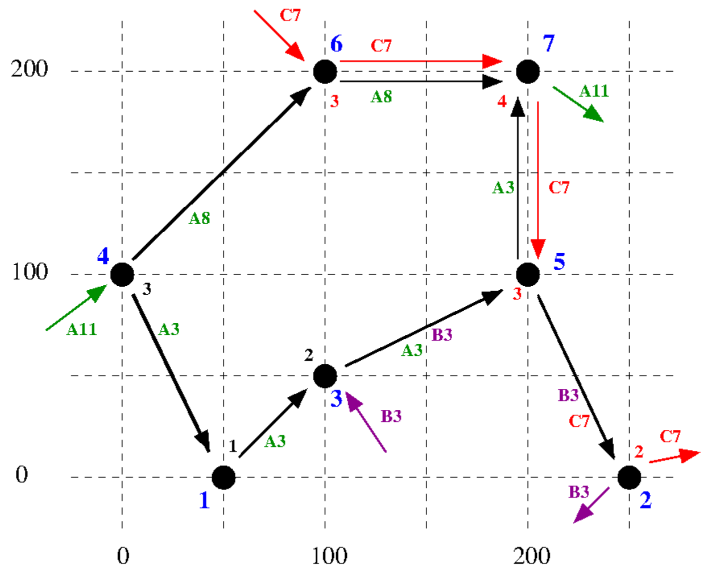
SmallRail now needs to expand its network to handle additional shipments:

- **Scenario 1:** A new shipment C has to be added that transports seven units of goods from station 6 to station 2.

In general, a network can be increased as follows:

- A new reloading station can be added at the cost of $1,000,000. (We will later consider other costs.)
- A new track can be built aside an *existing* track. The cost of a new track is $5,000 per mile.
- A new line can be established between stations that are not currently connected by tracks, as long as the distance is not larger than 220 miles. Paving the way for a new line is $7,000 per mile. This is in addition to the $5,000 per mile to build the new track.

Let's consider two different ways to augment the network for Scenario 1:

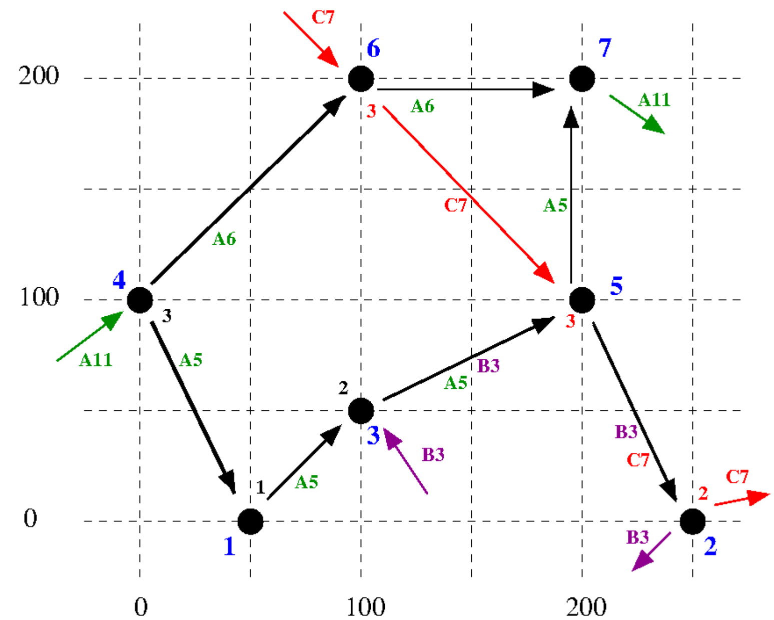


You can see the new shipment in red. The following modifications were made:

1. Add a new track between stations 6 and 7. This is used to ship the total of 7+8>10 units of goods from 6 to 7. This costs $5,000/mile * 100miles = $500,000.
2. Add a new track between stations 7 and 5. This is used to ship goods in the other direction than what is currently shipped from 5 to 7. (Note that the total shipment between 5 and 7 is 3+7=10, but the opposite directions cannot share one track). This costs $5,000/mile * 100miles = $500,000.
   Note: We do not need to add a track between stations 5 and 2, since we can use the existing track, since the shipments are going in the same direction and the total volume does not exceed the capacity of a single track.
3. A new reloading building is added each at Stations 6, 7, 5, and 2 to handle the increased volume of incoming goods. This costs 4 * 1building * $1,000,000/building = $4,000,000.

The total cost for this modification is $5,000,000.

Now let's discuss an alternative modification of the network:



Now the following modifications were made:

1. Add a new line and a new track between stations 6 and 5. This costs ($7,000 + $5,000) * 141.77 = $1,701,240. Recall that we first need to add the line before we can build a new track. Also note that the distance of 141.77 miles is less than the limit of 220 miles.
2. A new reloading building is added each at Stations 6, 5, and 2 to handle the increased volume of incoming goods. This costs 3 * 1 * $1,000,000 = $3,000,000.
3. Note that we also decided to change the routing for shipment A: We now send 6 units of goods via 4-6-7, and 5 units via 4-1-3-5-7.

The total cost for this modification is $4,701,240. The new network is given in the following tables:

Station	x-coordinate	y-coordinate	# existing reloading buildings	Costs
1	50	0	1	
2	250	0	2	1,000,000
3	100	50	2	
4	0	100	3	
5	200	100	3	1,000,000
6	100	200	3	1,000,000
7	200	200	3	

Station	Station	# existing tracks	Costs
1	3	1	
1	4	1	
2	5	1	
3	5	1	
4	6	1	
5	7	1	
5	6	1	1,701,240
6	7	1	

Shipment	Origin	Destination	Total volume	Path	Path volume
A	4	7	11	4-6-7	6
				4-1-3-5-7	7
B	3	1	3	3-5-2	3
C	6	2	7	6-5-2	7

Your task in this project is to help the SmallRai determine the network modifications with the smallest costs.

The first phase of the project does not require much material from class and instead relies on your common sense: use whatever methods you like—apart from solving optimization problems (such as LPs or MILPs), or trying out all possible network changes (there are too many!)—to find the cheapest network modification for a given scenario you can find. Such a method that aims to find a good solution but does not necessarily find the optimal solution is called a *heuristic*. You need to describe this method in very clear and unambiguous steps, so that SmallRail can use it later for other networks and other shipment changes.

Apply your method to find network modifications for the following two scenarios (always starting from the base case):

- **Scenario 2:** A new shipment C has to be added that transports nine units of goods from station 4 to station 2.
- **Scenario 3:** Two new shipments need to be added: Shipment C for eight units from station 6 to station 3, and Shipment D for four units from station 7 to station 1.

We also consider two different costs for adding a new reloading building: \$1,000,000 per building (as above) and \$500,000 per building.

Phase I (due May 11):

You are asked to find four different network modifications and routing plans: Two for each of Scenario 2 and 3, with \$1,000,000 and \$500,000 costs per reloading building, respectively.

In this first phase, you need to develop a heuristic to find good (optimal?) network modifications. Your method should be simple to implement, and should not use mathematical programming (i.e., LP or MILP formulations) in any way. Your method should be general and applicable to any network and list of shipments. One way to think of this is to imagine that you are going to program your methods in Matlab or in another programming language (you might actually choose to do so), and you do not know the data (including the existing network and new shipments) beforehand.

The deliverables:

1. You should submit a report (PDF format) that is no more than 7 pages:

   - One page describing your method with clear step by step instructions.
   - One page that explains the justification for why you think this is a good method. Why do you think that your method will provide good solutions?
   - One page discussing potential shortcomings of your method. What could be done better? Any idea how to handle this? How does the executing time of your method increase with the size of the network and number of shipments?
   - One per scenario/reloading building cost, giving the final modified network structure and routine plan, using the same table format as above (three tables per case).

   You should think carefully about how to describe your method concisely. Describe the method in a general way (step by step instructions), so that *someone else* could apply the same ideas to a different scenario. That is, you should describe what steps should be followed to take the information provided and develop a production plan. Make sure you are very precise, so that everyone can follow your instructions literally without ambiguity or guesswork. If your description is too complicated to understand, you will not receive full credit

Here is an example of such a description (probably not a good method):

1. Pick a new shipment with the smallest volume (if there is a tie, pick the one that is listed first)
2. For this shipment, do the following procedure:
   i) Choose the path with the longest distance from origin to destination (HOW EXACTLY IS THAT PATH DEFINED? WHAT IF THERE IS A TIE?)
   ii) Starting from the origin, do the following steps for each station along the path:
      a) Add two new tracks between the current and the next and route all units of goods along these tracks.
      b) Go to the next station along the path.

2. You should submit an appendix (PDF format, can be in same file as the report) to your report. It should illustrate the steps of your method on the data in Scenarios 2 and 3, both costs of $1,000,000 and $500,000 per reloading building. Make sure your illustrations are clear, but be concise.

   Alternatively, you can write a computer program (Matlab, python, C++, whatever you want) that executes your heuristic. Describe how the network structure and shipments should be entered into your program.

You need only submit one project per group. You can design your own method or you can research methods designed by others. If your method is a result of research and is based on a method developed by someone else, then you must cite your source. In either case, you must discuss the justification and motivation for the method.

You will be graded based on your creativity in solving the problem and on the depth with which you explore and understand each problem, based on the clarity of the description, justification, and execution of your method, and based on the overall presentation of the results. (This will be graded very strictly; receiving full credit will be difficult.)

BONUS PROBLEM:

If you want to be challenged and receive some extra credit, apply your method to the following large example:

- Set of stations

Station	x-coordinate	y-coordinate	# existing reloading buildings
1	0	0	4
2	50	50	5
3	250	50	4
4	400	50	4
5	0	100	6
6	250	100	4
7	150	150	2
8	300	150	4
9	50	200	4
10	350	200	6
11	150	250	3
12	100	300	3
13	400	300	7
14	250	350	4

- Set of tracks

Station	Station	# existing tracks
1	2	2
1	5	1
2	3	2
2	5	2
2	7	1
3	4	3
4	10	2
5	9	3
6	7	1
6	8	2
8	10	2
9	12	2
10	13	3
11	12	2
11	14	2
13	14	3

Currently, SmallRail is operating five shipments, given in this table:

Shipment	Origin	Destination	Total volume	Path	Path volume
A	1	13	17	1-5-9-12-11-14-13	9
				1-2-7-6-8-10-13	5
				1-2-3-4-10-13	3
B	5	10	8	5-2-7-6-8-10	5
				5-9-12-11-14-13-10	3
C	9	4	8	9-5-2-3-4	8
D	14	3	7	14-13-10-4-3	7
E	13	6	6	13-10-8-6	6