Sea and Land Shipping - General Electric

Engineering Design 100
Section 022
Dr. Ritter
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The Baconators
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Abstract
GE had brought to our attention the issue of excessive smog in the city of Pittsadelphia because of emissions from trains. We were asked by GE to come up with a way to reduce NOx emissions from trains while considering the cost of the project and not causing any disruptions of any kind to the city of Pittsadelphia. Our group had created a list of customer needs that we felt appropriate and we ranked these needs in an AHP matrix. Using the weights from our AHP matrix and our list of ideas we had previously brainstormed, we made a concept selection matrix and eliminated all but two of our ideas. After selecting a final idea, we met with other teams to discuss our idea and after receiving feedback on our idea we decided to modify our idea. We will sell forty of our trains, upgrade the remaining ten to tier 4, buy ten new tier 4 trains, and charter 3 ships. The trains will be used to transport coal from West Virginia and the 3 ships will be used to charter freight from Miami. In conclusion, this idea allows us to surpass the set customer needs and provides us with an immediate profit.

Introduction & Problem Statement
The city of Pittsadelphia ships out and receives around 165,000 tons of freight and minerals, daily. The city solely uses EPA Tier 2 locomotives. This tier of locomotives is becoming outdated as they produce NOx emissions above EPA regulations. These NOx emissions have led to smog surrounding the city and residents are upset.

GE Transportation has come to us and requested our help in addressing locomotive emissions. They have suggested several options, such as upgrading the locomotive fleet or using other shipping methods. We could upgrade the locomotive fleet by using these general methods: selling current locomotives and purchasing new ones, using exhaust after-treatment hardware, or implementing alternative fuels such as natural gas or biodiesel. Alternative methods include using ships, planes, or trucks. It is also an option to combine any of the previously mentioned options to create a system that minimizes the amount of NOx emissions the most efficiently.

Pittsadelphia aims to reduce NOx and PM emissions and abide by EPA regulations. Smog has become a serious concern in Pittsadelphia and it is time to make changes to reduce the amount of toxic emissions coming from locomotives. At this point, Pittsadelphia locomotives are not within the current EPA regulations and need to make adjustments to their system. These changes could be implemented through train upgrades or newly purchased trains.

We will investigate how they can improve on NOx and PM emissions while keeping the cost relatively low and having a healthy return on investments. Our goal is to reduce emissions by more than 70 percent. We need to weigh various solutions against one another by comparing how each meets the needs, such as low environmental impact, freight capacity, and on time delivery. Some of these solutions may involve alternate forms of transportation such as ships, planes, or trucks. The mission of Pittsadelphia is to find a solution that is the most beneficial to the environment as well as freight delivery.
Background

Much of the information provided to us by GE was very useful in helping our group make decisions on our project. However, in order to expand our knowledge of other modes of transportation besides trains, a bit of research was required. We learned from the “Shipping Industry Comparators” chart that was provided to us in the “Project Background” powerpoint that ships are very cost efficient and environmentally beneficial. This information given to us was a gateway into our research of transportation by sea.

A big part of our reasoning for using ships to transport goods was the projection that by the year 2020 ships as a means of transportation was going to increase and the popularity of ships was only growing [10]. Our first thought was to purchase a cargo vessel, but we found that the cost of a new medium sized cargo vessel is around $75 million [5]. This led us to research the cost of chartering a cargo ship. To charter a ship and crew for a day costs about $10,000, which is much more reasonable [3]. We then had to decide where our freight would be shipped from. From the requirements of the port being 500 miles away, we decided that we wanted to be able to make the trip within three days, round trip. This led us to the port of Miami, which is about 900 miles from Pittsadelphia, is a deep water port, and has crane equipment to unload over 100 ton containers [7]. We decided to have our coal shipped from West Virginia because West Virginia provides 12 percent of the nation's coal and is in close range of our target city, Pittsadelphia [8]. Overall, our research mainly consisted of information from GE, but several of our decisions were determined by outside sources.

Customer needs

Our team chose to evaluate our designs based on the following customer needs: low NOx emissions, fits clearance requirements, weatherproof, low maintenance, satisfies EPA requirements, on time delivery, freight capacity, return on investments, fuel cost, and fuel efficient. We decided to choose this criteria for many different reasons. Our team included low NOx emissions, and satisfies EPA requirements because that is ultimately the goal of this project. Another issue that we felt needed to be satisfied was fitting the clearance requirement. If our design did not fit the clearance requirement then it would not be able to run and therefore our design would serve no purpose. Freight capacity was also important to us because we wanted the city to be able to continue working with the same amount of freight that they were originally without being negatively impacted by the changes we have made. We decided to include weatherproof in our requirements as well because we wanted our design to be able to function all throughout the year without any major delays or complications. Low maintenance was incorporated into our needs because we did not want to add additional costs of frequent maintenance to our design. On time delivery was important to our group because if not on time it could cause major delays elsewhere and cause serious problems. Another need we felt was required was return on investments; we wanted to make sure our product would produce a profit within a decent amount of time. To have our product be fuel efficient and have a low fuel cost was also a need for our group.
When all of our customer needs had been finalized we put them into our AHP matrix. We based our ratings off of the topics that we found to be most influential on the project all together. We felt that every customer need was crucial to the overall design of our product and therefore they are all ranked pretty closely on our AHP matrix. It was hard for our group to give ranks because we felt that all topics were important but based on our chart we find that fit clearance requirement, satisfies EPA requirements, low NOx emission, and return on investments have the highest rankings. Our group felt that this ranking was very appropriate. We wanted to make sure that our product satisfied these particular customer needs because without the product fitting the clearance requirement it can not run and without satisfying EPA requirements and lowering NOx emissions our product did not meet the objective of the design. Also, return on investments because it was very important to our group to keep our costs low.

**Concept Generation**

After underlining the problem statement, customer needs, and understanding what it was GE was asking of us, we began the initial process for concept generation. The first thing we did in the process of concept generation was that we all individually generated as many ideas as we possibly could to maximize creativity and the time given to us. Keeping the main idea very simple, which was to get cargo from point A to point B in as many different ways, allowed us to think broadly, and generalize, which eliminated the tendency to get fixated on one idea. We all given design generation cards and pens and started working. In the 30 minutes we were given, we were all able to collectively generate 9 ideas, most of which were different from one another which really helped our discussion of the ideas. We were able to give constructive criticism of each other’s ideas while finding the pros of the ideas. Reflecting on each other’s ideas informally like this was very useful in that it helped us make certain conclusions that quantitative methods may have overlooked. Below are all the initial designs:

**Figure 1:** Above is the AHP matrix in which we evaluated the importance of our customer needs.
Concept Development, Cost- Benefit Analysis, and Selection

As stated previously we created our ideas in a very informal style, basically jotting down anything that came to mind and worrying about feasibility, and cost later. After we generated approximately nine ideas, we immediately eliminated four ideas because we knew that even if they won the concept scoring we were not going to follow through with them. This part of the selection was very informal, there are no numbers to back our reasoning it was simply a team consensus. The four we eliminated were, in our opinion, either too similar to a dominant solution or were clearly not feasible. From there we inserted the remaining five solutions into a concept
selection matrix. This matrix was the formal aspect of our selection and provides quantitative data to back our findings. For this scoring matrix we took the weights that we calculated for each of our customer need, we got the weights from the AHP chart mentioned above. From there we ranked the five ideas against the customer needs. From there we got a total which we then put in numerical order, the higher the score the better the solution. All of these calculations and figures can be seen in table, shown below. Following this rating we reverted back to informal methods of selection. We immediately eliminated idea #4 and #8 because they had the two lowest scores. We all agreed that we would continue to consider idea #1 because it came in first place. The trouble we ran into was deciding whether we should further evaluate idea #2 or #6. Solution #2 scored third in the matrix and was the option of taking a boat to a port followed by a train into Pittsadelphia. This solution scored extremely well for freight capacity, and fuel efficiency. However adding boats to the solution makes it difficult to ensure on time delivery, which is a major flaw in the system. Idea #6 got second place in the scoring and was the option of taking a boat to a port followed by a truck to Pittsadelphia. The idea scored well when it comes to fuel cost along with fuel efficiency. The biggest issues with this are the NOx emissions and as solution #2 there would be a lower guarantee for on time delivery. Solution #6 was ranked higher by the matrix however after discussing with my group we decided that the criteria was a lot tougher on trains because when making up the customer needs we had trains in mind. This meant that for some of the areas trucks and boats were able to get by without truly being judged because the criteria simply did not match up with the mode of transportation allowing for those ideas to score higher. We proceeded to look into a few other factors like timeliness of boats and trucks, their freight capacity, and their environmental impact. From there we decided to move forward with solution #2 as our final design. It brought in the new aspect of boats and still included trains, for our group it was the perfect mix. We decided it would be a much more interesting solution than just upgrading all of our trains that’s why we got rid of idea #1.

**Table 1:** The table below is a screenshot of the scoring concept selection matrix. It gives numerical values in order to rank solutions in order of effectiveness according to the scoring.

<table>
<thead>
<tr>
<th>Feature / Requirement (weight)</th>
<th>Low NOx Emission (0.1)</th>
<th>Fits Clearance Requirements (0.17)</th>
<th>Weather Proof (0.08)</th>
<th>Low Maintenance (0.05)</th>
<th>Satisfies EPA Requirements (0.14)</th>
<th>On Time Delivery (0.09)</th>
<th>Freight Capacity (0.09)</th>
<th>Return On Investments (0.1)</th>
<th>Fuel Cost (0.09)</th>
<th>Fuel Efficient (0.09)</th>
<th>Totals</th>
<th>RANK (1 best)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Train the entire way to Pittsadelphia</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3.97</td>
<td>1</td>
</tr>
<tr>
<td>#2 Boat to port, train to Pittsadelphia</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.89</td>
<td>3</td>
</tr>
<tr>
<td>#4 Train to stop, truck to Pittsadelphia</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3.7</td>
<td>4</td>
</tr>
<tr>
<td>#6 Boat to port, truck to Pittsadelphia</td>
<td>3</td>
<td>5</td>
<td>4.5</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3.92</td>
<td>2</td>
</tr>
<tr>
<td>#8 Plane to airport, truck to Pittsadelphia</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3.52</td>
<td>5</td>
</tr>
</tbody>
</table>
Cost-Benefit Analysis

Once the final design was selected it was time to move onto the cost analysis phase of the project. This is where a lot of the small hiccups in the design were sorted out and basically made our original idea feasible. The following calculations are what we used to solidify our final solution and ensure it was the best it could be. For this section we chose to find the cost of our final solution along with the cost of GE is currently functioning. This is so we can compare them later on to see how much we are truly saving.

GIVENS:

- Amount of tons needed to be moved per day:
  - 165,000 tons
- 60,000 tons moved by mineral trains: 4,000 tons per train (15 trains allocated to minerals)
- 105,000 tons moved by freight trains: 3,500 tons per train (30 trains allocated to freight)
- There are always 45 trains moving at a time and five extra in case of emergency.
- Costs 1.25 mill to upgrade train to tier 4 from tier 2
- Costs 4 mill to buy a new tier 4 train
- A profit of 1.5 mill for every tier 2 train sold
- About $3.06/gallon for train fuel

GE CURRENTLY

Table 2: This table accounts for fuel cost of trains. Their fleet: 50 tier 2 trains

<table>
<thead>
<tr>
<th></th>
<th>30 freight trains</th>
<th>15 mineral trains</th>
<th>Total Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/ day</td>
<td>321,300</td>
<td>183,600</td>
<td>504,900/ day</td>
</tr>
<tr>
<td>Cost/ year</td>
<td>115,668,000</td>
<td>66,096,000</td>
<td>181,764,000/ year</td>
</tr>
</tbody>
</table>

Team 8 Solution

Four our teams solution we had to look into prices for purchasing cargo ships, the prices were extremely high and we were not willing to pay. At that point we thought our entire design was going to fail however we then considered the idea of chartering ships. These charters were well within our price range, at only about $10,000/day (Hollmann, Michael). This made our plan totally feasible, we further researched chartering and found that at this price fuel cost is included as well as deck hands. Not only was this well within our price range but it ended up saving us an enormous amount of money. From here we made the decision to ship all of our freight by cargo ship.

Creating the new fleet:

- Selling 40 trains: 60 million
- Upgrading 10 trains (tier 4): 12.5 million
Buying 10 new trains (tier 4): 40 million

60 million revenue
12.5 million in cost
-40 million in cost
7.5 million initial revenue

The new fleet:

**Table 3**: This table accounts for fuel cost of trains along with the chartering of cargo ships. This fleet consists of 20 tier 4 trains and 3 capesize cargo ships.

<table>
<thead>
<tr>
<th></th>
<th>3 boats (freight)</th>
<th>20 tier 4 (mineral)</th>
<th>Total fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/ day</td>
<td>30,000</td>
<td>183,600</td>
<td>213,600/ day</td>
</tr>
<tr>
<td>Cost/ year</td>
<td>10,950,000</td>
<td>66,096,000</td>
<td>77,046,000/ year</td>
</tr>
</tbody>
</table>

COMPARING THE TWO FLEETS:

**Table 4**: The table below compares the old fleets yearly and daily pricing in comparison to the newer fleet.

<table>
<thead>
<tr>
<th></th>
<th>Old Fleet</th>
<th>Team 8- Updated Fleet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/ day</td>
<td>504,900</td>
<td>213,600</td>
</tr>
<tr>
<td>Cost/ year</td>
<td>181,764,000</td>
<td>77,046,000</td>
</tr>
</tbody>
</table>

**The Final Design**

Our updated fleet is the dominant fleet of the two. It costs less in fuel and chartering than the old fleet and it has the revenue that will be gained initially. We will save $104,718,000 yearly not including the initial revenue from selling the 40 trains. After all of these calculations we found that we will have a return on investment right away because of our profit after selling 40 tier II trains. Not only that but after making changes to the design (making the trains transport the minerals and the ships handle the cargo) we were able to re-score on the concept scoring matrix and found that this modified solution placed in first compared to the others. The solution capitalizes on environmental safety because ships aren’t as harmful as trains so by cutting down on trains we are able to eliminate NOx emissions. Ships also have a very large capacity and we would be able to fit the daily freight income onto one ship, the reason for purchasing three is so we will be able to be on time and have a delivery coming into port once a day. None of the other designs were able to satisfy the criteria as well as the final solution, let alone do it on this small of a budget.
**Design Review**

Overall, the design review was beneficial to our final design. Other groups were very receptive of our idea and understood what we wanted to do. The groups that we met with liked our idea of selling some of the trains, upgrading some of the trains, and buying some new trains. Our idea overall was feasible and reduces smog. However, other groups did help us to figure out some parts of the project that we had left out. One of the things that our group neglected to think about was using any types of alternative fuel. It was brought to our attention that if we switched to an alternate fuel it may help to reduce the amount of smog even further. It was also suggested that our group do more research on the incorporation of our idea into the larger system. Another concern that was brought up to us was that when using our ships we need to consider sea costs - which we had neglected to think about.

The design review helped us to reevaluate the original idea that we had selected. After the design review we took a step back and looked at our design from the outside. We decided that it would be more beneficial for us to transport all coal by train from West Virginia and all freight by ship from Miami instead of switching from a boat to a train. We also reconsidered the costs of buying a ship versus chartering a ship and we found that it would be less expensive to charter a ship.

**Final Design**

Our teams final design is to transport 60,000 tons of minerals per day from West Virginia using twenty tier 4 trains. As for the 105,000 tons of freight per day we will be chartering 3 capesize cargo ships to transport the freight from the port of Miami, Florida. This design saves us time money and reduces NOx emissions. Below is our model/prototype which displays the changes we will be making to our original fleet. We will sell 40 of our tier 2 trains (yellow -> grey) for a profit of $60 million. Then we will upgrade the ten remaining tier 2 trains to tier 4 which costs $12.5 million represented as green in the diagram below. We will then buy an additional 10 brand new tier 4 trains for $40 million seen as blue in the figure below. Finally we have introduced a new mode of transportation, cargo ships. We have opted to charter three ships at a time shown in the red below, they will be used solely to transport freight from Miami.
Figure 2: The image above is our teams model/prototype for the final solution. We used color coding in order to display the changes made from the old fleet to the new one.

Rationale of Solution

There are many reasons we chose to select this option as our final design. The regulations set out by the EPA call for all trains to be upgraded to at least tier three. Our design satisfies this criteria and we chose to go a step further to tier 4. We made this decision because it's only a matter of time before the regulations are raised to demand at the least tier 4. This will prevent us from having to upgrade our fleet in the near future. We have successfully reduced our NOx and PM emissions. As for cost we are producing an immediate return on investment which will only help to get support. Not only are we starting out with a profit of 7.5 million in initial revenue but we will also be saving $104,718,000 yearly. Those majors savings come from the lack of fuel we need to run our fleet. By selling the majority of our fleet and replacing it with three chartered cargo ships we make unbelievable savings ("How Does Chartering Work?"). There are no modifications needed for our new system, all of the material will be brought directly to Pittsadelphia’s port and distributed to the city from there. The freight capacity is not an issue, if anything we would be able to transport more freight by ship than we originally could have done with the 30 trains that used to be used for freight transport. The public will be very accepting of this idea, there are no moral dilemmas, the environment will be bettered from this solution, money will be saved and we will not be adjusting the infrastructure at all so there will be no complaints in regards to that. Finally deliveries will be timely, the mineral trains are of no concern because trains are known to have sufficient on-time delivery. Boats are not the best when it comes to on-time delivery however our ship route is not long and we have three ships in rotation. It will take a ship less than three days to make a round trip, this means we will be able to have a daily delivery in the Pittsadelphia port. Our final design addresses all of these key aspects and excels in the majority of the criteria, there is work to be done on the system but overall I believe the system will be successful.
Environmental Analysis

One of our main goals for this project was that we proposed a model that would improve the environmental aspect of the freight transportation. By this we mean that we aimed to meet the current EPA regulations by reducing the emissions of NOx (Nitrogen Oxide) and PM (Particulate Matter). Nitrogen Oxide creates smog which is a huge problem to the people of Pittsadelphia, one because it is so prevalent, and also because of the health problems it causes. Smog can cause damages to the lung tissue and reduce lung function. Particulate Matter is also very harmful in that can restrict lung function and cause chronic bronchitis. With all this in mind it became clear that we had to fix this issue.

The first thing we did was looked at the benefits of buying new tier 4 trains, and we were pleased to see that this improved NOx and PM emissions greatly. The graphs below illustrate the data that we were able to find on this:

![Graphs of NOx and PM emissions for Tier 1-4 trains](image)

From the graph on the left you can clearly, just at a glimpse, see that both PM and NOx emissions (in g/bhp-hr) is reduced outstandingly from tier 2 to tier 4. To get exact values we looked at the chart on the right. As you can see, Tier 2 trains have a value of 8.1 g/bhp-hr for NOx emissions and a value of 0.13 g/bhp-hr for PM emissions. Buying the new tier 4 trains reduces the NOx emissions value to 1.3 and the PM emissions value to 0.03. Both of these...
values meet the EPA requirements so we fulfilled our goal of meeting these requirements, in fact we exceeded this goal.

The next step was to look at how a medium sized cargo ship compared to a tier two train. For the NOx emissions we found that recent laws meant that medium sized cargo ships emitted 80% less Nitrogen Oxide. This reduces emissions from 0.045 g/bhp-hr to 0.01 g/bhp-hr. For particulate matter it was a very similar case. There was a recent 96% decrease in PM emissions on average among cargo ships at of 2015. It reduced PM emissions from 0.045 g/bhp-hr to 0.01 g/bhp-hr also. Knowing all of this information we knew that our idea would greatly improve the freight transportation environmental impact.

Feasibility

The system will not call for much adoption and is very feasible. Since we are using boats to transport the freight we don’t have to worry about laying new tracks for the trains or maintaining those tracks. By chartering a ship we are handing off a lot of the work to the chartering company. They are responsible for maintenance, port space and fueling. This leaves very little for GE to do in terms of making sure the ships are running smoothly. Pittsadelphia is a port city so there is no need to find which port would be nearest to the city and how to transport it there, the boat would go directly there. Also the time for the ship to travel to Miami and back is less than three days and by having the three ships we will have little issues making the deliveries on time. As for the mineral trains the voyage to West Virginia is very simple and the rail lines already exist. The trains will be able to make it there and back within the day.

Economically we are just as feasible. We not only are saving money but the first year we will be ending in the green zone. There is an immediate return on investment. This is due to the selling of the 40 tier 2 trains in the beginning of the transition of the original fleet to the updated one. We also have major savings due to chartering ships rather than spending money on the trains needed to move the same amount of freight. All of these findings can be viewed in the Cost- Benefit Analysis of the document, stated previously.
Figure 3: Above is our final solutions system diagram. It shows the inputs and the outputs through the steps of transportation.
Concept of Operations

Figure 4: Our conceptual operations chart, showing the system of cargo ships and trains moving freight and coal, respectively.
Conclusions

Overall we feel like our new implemented system will really change the outcome of freight transportation in and out of Pittsadelphia. In this model, we successfully were instantly able to make a profit by selling the old tier 2 trains. Even with purchasing new tier 4 trains and renting ships, we were already in the clear with breaking even. With the increased efficiency we were would be also continuing to make more profit each day. Another positive aspect to this model is that the NOx and PM emissions are reduced greatly meaning that less smog is produced, leaving the people of Pittsadelphia happier and healthier. The only issue we could find with this model is that it may take some amount of time to implement however once everything is in place, the benefits become prevalent almost instantly.

From here the model will be able to sustain itself and still make a profit until the a new tier of trains is released. Then the same model can be used but instead of selling tier 2 and buying new tier 4, you would instead sell the tier 4 and buy the new tier 5 trains. The same principle stands for the ship renting. If new, more efficient ships are available to rent then you would simply change the ships you renting from the old ones to the new ones. This means that this model can stay efficient and worthwhile for as long as Pittsadelphia needs freight transported.

The main lessons that us as a group learned from this project was to manage our time effectively, collaborate, be honest, and to not leave things to the last minute. At the start of the project we did not effectively manage our time and ended up finding ourselves pushed for time towards the end. However as time went on we budgeted the right amount of time for each assignment and got everything done on time. One of the most important aspects of the project was reflecting on each other's work well. This helped us make improvements that we wouldn't have known to make by ourselves. Overall the project helped us work better in groups.
References
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