GE Final Project
Philadelphia

Engineering Design 100, Section 025, Dr. Ritter

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JCP Engineering

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Abstract

As evidenced by the present United Nations Climate Change Conference being held in Paris, air pollution is a very real and imminent threat to present and future generations. In order to reduce the impact of smog, the ecological change must start small. The municipality of Philadelphia has decided to change its shipping infrastructure while maintaining its productivity of 165,000 tons. Keeping in mind the needs of our customers and stakeholders, JCP Engineering utilized the design process to devise a creative system that optimizes cost, effectiveness, time, productivity and most importantly, emissions.

Problem Statement

JCP Engineering has been presented with a proposal from the municipality of Philadelphia to design a freight shipping system that reduces smog through an upgrade to Tier III locomotives, improves the time and output of production, and will start generating revenue after two years. All of the aforementioned criteria will be utilized while yielding public safety and approval, and also maintaining the present infrastructure for locomotives.

At present, locomotives are utilizing Tier II locomotives that run on diesel as their primary source of fuel. The current system ships 105,000 tons of freight and 60,000 tons of coal to Philadelphia per day. Complaints from the general public call for a reduction in NOx emissions, and new EPA requirements will necessitate an upgrade from Tier II locomotives.

To meet the proposed criteria, we as JCP Engineering will work through the design process to yield the best solution for amending the infrastructure. We will take into consideration concept generation and selection, cost-analysis and feasibility, and emission reduction while using research techniques and various methods, such as an AHP matrix to weigh customer needs.
Background

Our group knew right away that we wanted to reduce emissions in a unique way for our shipping route. We viewed slides presented to us by GE that had different ways of transporting goods such as through the air or via truck. We were intrigued with the idea of shipping from a port city, which granted us access to using a ships as a way to move our goods. We were able to stumble upon a website run by the Tennessee Tombigbee Waterway. This website showed us that barges could carry much more freight than a locomotive could. We reviewed the site more and discovered that emissions for barges were also safer and more environmentally friendly. We knew immediately that using barges as opposed to trains for a portion of our route would be a cheap and effective way to reduce our emissions.

To implement our barge system, we had to buy barges. We researched different websites trying to find home much it would cost to purchase the size of barges we needed. A website run by the Coosa-Alabama River Improvement System relayed to us that a new barge with a 1600 ton capacity would have a construction cost of 225K. We needed to buy 70 barges in order to transport all of the freight in 1500 ton increments, so $15.75M would be needed to cover this cost.

We turned to the GE slides on Angel to find out information pertaining to the locomotives. Here we discovered that each locomotive upgrade from Tier II to Tier III would cost $750K. We also were able to find that the price of B20 Biodiesel is 14 cents cheaper that the standard petroleum based biodiesel that is currently used by GE.
**Customer Needs**

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**Figure 1.** The AHP Matrix aided in concept selecting by giving a weight to each customer need.

JCP Engineering collaborated on what specific aspects are important to this project, and came up with a list of criteria that our solution must satisfy in order to be successful. Our highest priority need was reducing emissions. Clearly the most important, satisfying this criterion would solve the central problem of reducing smog itself. The second highest in priority was that our trains would meet size constraints so that the existing infrastructure for their passage would not need to be uprooted. The disestablishment and reconstruction of such an infrastructure would be extremely costly and would delay the project. The third most important was fuel efficiency. To cut down on the cost of fuel and heighten productivity, would have to make more use of our fuel and allow for less refueling. Fourth on our list was the interference of the system. Based on our decision that reduction of smog would not be subsumed into this category, the system’s interference would mainly deal with its general inconspicuousness, which is also a very
important factor for putting a design into context. Cost effectiveness and maintaining of production and capacity were ranked similarly because of their roles in feasibility. Being able to ship the same tonnage at the same rate and reduce costs are some of the main proponents to this system (even more so than the matrix showed). Last on our list was ease of maintenance. Due to the fact that these trains and barges are already constructed (the engineers that built them went through this same process), they will have already been optimized to resolve this issue.

**Concept Generation**

When we first began producing concepts, our team did so through the TASC assignment. The goal of this was to produce as many ideas as possible, regardless of feasibility at that particular moment. From the beginning, we generated a plethora of ideas, most of which involved the inclusion of an alternative method of shipping. Such methods included shipping through air and water as well as on land. Once we were finished creating potential ideas, we, as a team, began compiling a list of considerable and inconsiderable ideas. We reduced a little over a dozen ideas to the three that we felt were most beneficial given the circumstances. Two of the ideas explored the possibility of utilizing trucking as a form of shipment while the third considered using a barge somewhere in the model. Each idea also looked at the substitution of the current petroleum based fuel being used. We chose to move forward with these over other ideas because they seemed to be the most creative as well as the most feasible given the circumstances.

**Concept Analysis and Selection**

At this point in development, our team was left to choose which concept to further refine and ultimately declare as our model. Once again the TASC method was taken advantage of as
each of the three finalists were submitted to the program. From there, each team member went on the internet and anonymously chose from a given set of words that best described each idea. The program took those words and offered a number to describe each idea’s creativity. Although each scored well, the barge idea stood out at the time. We also used internet research when selecting a final concept and completed a cost-benefit analysis between each of our ideas.

Using our research and some of the given assumptions, we analyzed the feasibility of the models. The transportation that is chosen will move the freight portion of the cargo which is equal to 105,000 tons daily. Two immediate differences between using trucking and barges to move freight comes in the form of cargo capacity that we found on the Tennessee Tombigbee Waterway website. If each semi-truck holds 26 tons of cargo, it would require about 4039 trucks to move enough freight in order to maintain production to Philadelphia. A ship, on the other hand, can hold much more cargo, approximately 1500 tons per barge. Shipping would require 70 barges to move a sufficient amount of cargo, which is much more feasible to use. Buying the 70 barges would be an estimated $15 million cheaper than the 4000 trucks required according to the website by Coosa-Alabama River Improvement System as well as a website called CostOwl. It is also imagined that loading times for the barges would be less compared to the fleet of 4000 trucks that would be required for the other mode of transportation.

Barges also have much better safety and fuel efficiency than in comparison to the trucking counterpart according to the Tennessee Tombigbee Waterway website. Barges have approximately 0.01 deaths per billion-ton-miles compared to the 0.84 of trucking. This is a much lower value and can potentially save a number of lives in the long run. Barges also are much more energy efficient in terms of fuel efficiency. A barge on average will deliver cargo
using fuel at a rate of 514 miles/gallon carrying one ton of cargo. A truck on the other hand will only get 59 miles/gallon carrying one ton of cargo. As reported by the Tennessee Tombigbee Waterway website barges are much more environmentally friendly as well in terms of emissions, only producing 0.0053 pounds/mile carrying one ton of cargo of nitrous oxide. This is almost half that of a truck, much less than that of a truck, which produces 19 times as much nitrous oxide emissions. Barges also produce 70 times less hydrocarbons as opposed their trucking counterparts.

Trains will also be used in this model, both in the shipment of freight and coal. However, the current Tier II trains will be upgraded to Tier III, in order to meet the emissions standards set forth. It should also be noted that the shipping will be split into two branches. 105,000 tons of freight will be shipped to Philadelphia, Pennsylvania from Portland, Maine and 60,000 tons of coal will be shipped from Harrisburg, Pennsylvania to Philadelphia, Pennsylvania. As we explored different fuel options we found it beneficial to use trains running on B20 for fuel as opposed to petroleum based diesel, compressed natural gas or liquefied natural gas. B20 will produce less greenhouse gas emissions than the latter options, 52% less in fact according to the U.S. Department of Energy website. More specifically, B20 will be used, as the trains won’t require engine modifications to use it, reducing the initial cost compared to other fuels. Along with the reduction of emissions, B20 is relatively cheap based on numbers given by GE, selling at $2.92 per gallon as opposed to the $3.06 per gallon of petroleum based diesel. By these numbers, approximately $6.4 million would be saved annually on fueling costs.

Provided an initial investment of $53.25 million for the Tier III trains and 70 1500 ton barges, the fueling savings alone would provide a return on investment of around 8 years if the
barges ship the freight a fraction of the way. Alternatively, buying enough trucks to handle the magnitude of freight being shipped would cost an estimated $32 million at the cheapest in line with the CostOwl website. Not only would the implementation of trucks be less cost-effective overall, it would also produce more emissions than the barge concept. Clearly the barge idea is the most feasible being considered.

**Design Review**

After conducting two different peer review sessions with other teams, our group received valuable feedback on how to improve our model. One consideration made is to calculate the additional shipping time, if any, of using barges. While we believe there is a delay, we currently do not have a quantifiable statistic behind it. Another consideration made was to further improve the systems diagrams being used in order to clarify our model. Beyond that, one group brought the possibility of tax breaks into our eyes as well. If emission levels reach a certain threshold, the government may provide that company tax breaks, which can potentially make our model more economically feasible. Other than those concerns, our current model seems to meet most of the customer needs and upon further improvement based on these suggestions, should eventually meet all of the specific needs set forth.

**Final Design**

After going through the concept generation and concept development, we sifted through several ideas that the four of us thought were feasible. We ultimately decided to go out of the box a bit and substitute a portion of our shipping route from train to barge. Instead of using trucking to transport freight or using trains for the whole duration, we shipped the freight via barge from Portland, Maine to Plymouth, Massachusetts. This eliminated 184 miles that the
freight would travel on land. From Plymouth, the freight traveled 329 miles via Tier III train to Philadelphia. Our coal traveled directly from Harrisburg, Pennsylvania, to Philadelphia, Pennsylvania through Tier III trains.

Our major goal of this project was to reduce emissions from the shipment of the freight and coal. The upgrade for our 50 locomotives from Tier II to Tier III reduced our particulate matter emissions 70% and saved 84,425 kg of PM per year. To reduce our NOx emissions, we replaced a portion of the freight route with barge shipping. The barge shipping produces 29% less NOx emissions along with 20% less PM emissions that the Tier III trains. Our upgraded system saves 96,251 kg PM and 288,842 kg NOx annually.

Not only did we wish to improve emissions, but we knew we had to make this change happen within a reasonable amount of money. To help cover a portion of the cost, we decided to switch fuels. We switched from petroleum based diesel priced at $3.06 per gallon to B20 biodiesel which costed $2.92 per gallon. We were able to save $6.4 M per year simply by upgrading fuels. Upgrading to Tier III trains costed $37.5 M at $750 K per unit upgrade. 70 barges were purchased in order to ship the 105,000 tons of freight. Barges needed to be purchased costed a total of $15.75 M, a per unit price of $225 K.

By upgrading to barges, we were also able to reduce a typical shipping day from 24 hours to 22.5 hours. In this design we are assuming the barges are traveling at an average speed of 20 knots and the trains at 50 mph. This would increase the capacity of shipping we would be able to handle, and keep deliveries not only on-time, but slightly ahead of the previous schedule. We would be able to exceed the emission regulations set by the EPA by replacing part of the train route with a barge route.
To adopt our new system, GE must pay for the upgrade of 50 locomotives from Tier II to Tier III, and also purchase the 70 barges required for the barge route. As a group, we wanted to keep the costs of an upgrade at a feasible level, and to aid in this, we opted to switch the fuel used in the transportation of all cargo. As stated before, B20 Biodiesel is less expensive than the petroleum-based diesel used in Tier II locomotives. The savings of $6.4 million dollars per year and shipping time reduction allotted an estimated return on investment in six to seven years. This upgrade generates profit at the latest in seven years time, giving GE a feasible cost benefit for the improved system.

Figure 2: Final design model.
Given the requirements of reducing emissions while maintaining or improving the daily cargo shipped, our systems diagram shows exactly what will be inputted and outputted at each stage in the model. As our design is split into two sections, so is our systems diagram. The shipment of freight begins by inputting both fuel and freight into the fleet of barges in the port of Portland, Maine. Those barges then travel to Plymouth, Massachusetts, outputting both emissions and the freight that was originally inputted. The freight the barges output act as an input for the Tier III train portion of the design, along with more fuel. Once again emissions and freight act as the outputs, this time at the final destination of Philadelphia, Pennsylvania.

The coal shipment has very similar inputs and outputs as the freight shipment, just with different cities. Initially coal and fuel are inputted into the Tier III trains at Harrisburg, Pennsylvania. These trains travel the whole distance to Philadelphia, Pennsylvania, outputting emissions and the coal cargo by the end of the journey. This diagram helps depict how the cargo
tonnage will reach the final destination of Philadelphia and how emissions are a direct result of the transport.

**Concept of Operations**

![Concept of Operations](image)

*Figure 4: The concept of operations for the final design.*

**Conclusions**

Ultimately the solution we developed has its share of pros and cons, as does the majority of designs. The main issue at hand is the presence of smog in the city of Philadelphia, primarily caused by the emissions from the Tier II trains being used to transport goods. Our design effectively tackles that issue, placing the potential system well under the Tier III requirements placed upon it. This design also manages to maintain the cargo being delivered on a daily basis and even reduces the shipping times based upon the assumptions aforementioned. Another major benefit is the relatively low investment required to implement such a system. Compared to other designs that were presented, the fixed cost of $53.25 millions is very feasible. The cost of upkeep is also reduced through our model, mainly in the area of fueling.

However, this design does have a few cons to it as well. Most importantly, this design aims at a return on investment of around 6-7 years if the assumptions that were made hold
steady. This is more than triple that of the goal of 2 years, and higher than a few of the other designs that were presented. Another potential flaw is that the design, although it meets the required Tier III standards for emissions, does not meet those of Tier IV. This means that after a few years the design would have to be revised and to further bring down emission levels. Such action can potentially be costly.

If we were to continue building upon this design, one path we would likely take would be that of further train modification. Aside from upgrading to Tier III, we would have liked to further explore the possibility of utilizing an effective after-treatment to significantly reduce NOx emissions. Other, more effective fuel sources would have to be held in consideration as well.

As a design team, we learned about a couple topics. Most importantly, when we first completed our calculations for our environmental analysis we were very surprised at just how much emissions are being dealt with from these large-scale operations. The system we developed saved around 350,000 kg of emissions annually, a seemingly massive number. We were also rather shocked at how inefficient trucking is in comparison to alternative methods of shipping. Prior to the project we had expected trucking to be a reasonable form of transportation for these goods.
References


