Freight, Fuel, and Emissions
Introduction to Engineering Design

EDSGN 100
Design Project 2
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Submitted to
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Executive Summary

Our team was tasked to design and analyze the best possible method to reduce smog entering the city of Pittsdelphia, without increasing the cost or reducing the productivity of the industries by the Planning Commision of the city. The major constraints of the project that we needed to consider were cost, emission rates, freight throughput, public opinion, and whether the freight would still be able to enter the city on time. Our solution needed to reduce the NOx and PM caused by the system to meet the EPA requirements while maintaining the daily inflow of 165,000 tons of freight. After working on the best possible solution for a few months, we came to the conclusion that using a multimodal system that transports freight based off of the proximity to the final destination would be optimal. Our solution is theoretically able to carry all of the freight within the time period while also significantly reducing the smog produced.

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1. Introduction

This project was assigned to us by General Electric (GE). GE is a FORTUNE 500 company with an revenue of 148.59 billion dollars and a net income of 15.233 billion dollars. the company is divided into a number of divisions: Appliances, Oil and Gas, Aviation, Healthcare, Capital, Transportation and Power and water. It is involved in Home Appliances, Financial Services, Pharmaceuticals, Automotive, and a variety of other industries, mainly related to Engineering. The segment of GE related to this project (Transportation) manufactures locomotives and other equipment related to the railroad, marine, mining, drilling and energy generation industries. Since the goal of GE transportation (like any innovative company) is to further improve the industry and because of this, we have been tasked to design to reengineer the system used to bring in freight, into a more economical and sustainable one.

1.1. Design Principles

At the beginning of our project we identified the essential pillars that we would base our decisions off of throughout the design process. The critical pillars that we established were cost, pollution, public support, on-time delivery, creation of jobs, freight load, and effects on traffic. Two other pillars we also factored in to our design process were the Penn State Code of Ethics and all the Standards of ABET.

1.2. Gantt Chart

Chart 1 shows our teams Gantt chart which we used to pace ourselves over the course of this ten week project.

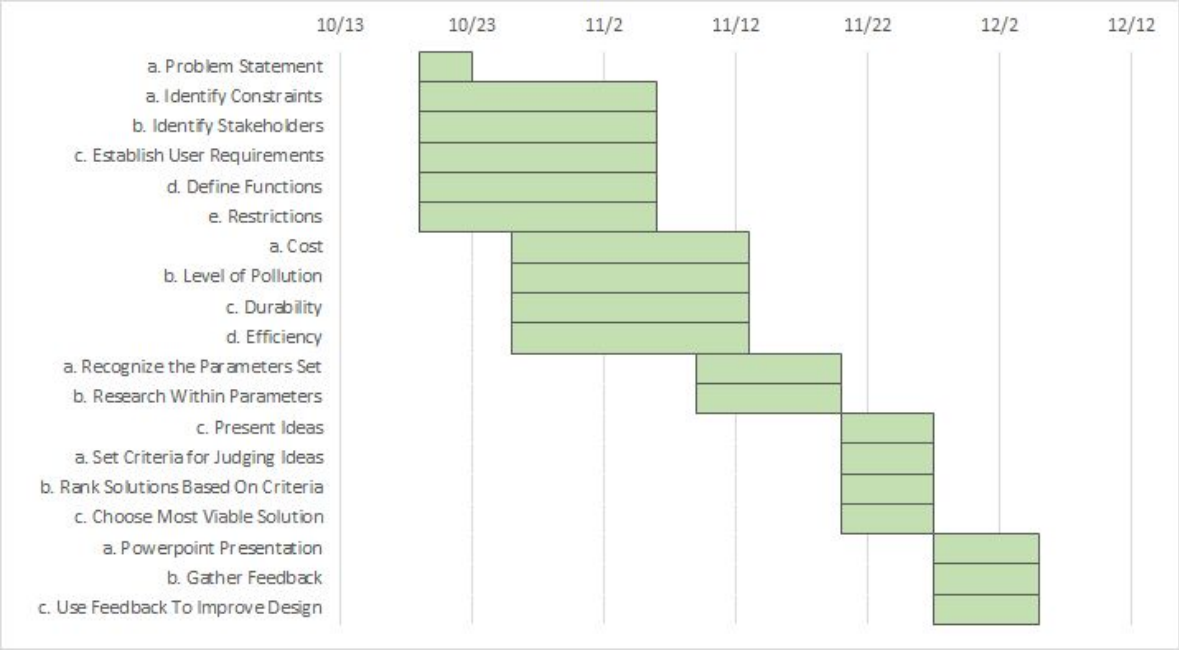

Chart 1. Project Gantt Chart

2. Project Background

General Electric came to Penn State with the goal to figure out how to reduce the levels of smog from locomotives in the city of Pittsdelphia. GE compiled various specs about their trains and the city and came to Penn State and challenged the students to use these to produce several ideas and pinpoint a practical and efficient idea that solves the city's problem.

The city's residents are complaining about the level of pollution in air. The EPA places emissions restrictions on trains and other vehicles and the deadline for GE's trains to be upgraded to Tier 4 is approaching. The new tier will require that the amount of PM and NOx be reduced. GE provided information regarding their trains' power output levels, parts, functions, and physical dimensions. They also included the costs of other solutions such as retrofitting and buying new trains and using alternative fuels.

GE also suggest using other forms of transportation, including ground, sea, and air. More information was compiled on the other forms of transportation from online research. Each mode of transportation is beneficial in a different area, such as speed, cost, freight throughput, and emissions. By analyzing these more and understanding their positive and negatives, we noted that a multimodal solution could be a possible solution to the city's problem. All of this information was compiled and compared to form feasible ideas.

3. Project Objectives

3.1. Problem Statement

Pittsdelphia receives about 165,000 tons of freight and minerals by train per day and the residents of the area area complaining because of the excessive smog emissions. The city planning commission needs a new more cost effective solution that produces less smog to satisfy the people of Pittsdelphia. The EPA has issued a new requirement for locomotives smog emissions, which are generated from NOx emissions, and the current tier 2 locomotives will have to be upgraded to meet the EPA requirements for tier 3. Possible solutions to make the transportation emissions going into the city cleaner are to sell the existing fleet and purchase new Tier 4 trains, install an after- treatment system onto the locomotive, use an alternate fuel source that produces less NOx, or use alternative freight shipping methods by plane, ship, or truck.

3.2. Stakeholders

Recognizing the stakeholders involved in the project is extremely important and must be done in order to appropriately approach the issue. The people of Pittsdelphia are our major stakeholder since they have identified a problem in their city and are the ones that must ultimately be satisfied. The Pittsdelphia planning commision is our second major stakeholder since they will be voting and determining the final solution for this problem. The EPA will also have a major influence throughout this process because of their new emission requirements on

locomotives. General Electric is another big stakeholder since they will be supplying the locomotives. Other companies, organizations, and authorities that will also be involved throughout this process are trucking companies, barge companies, train companies, and the Coast Guard.

3.3. Attributes

Consulting with our stakeholders allowed us to gauge what attributes are desired in the final outcome of our project. After discussions with the Pittsburgh planning commission, we narrowed our focus onto nine major attributes, each of which varied in importance. These are shown in **Table 1**. Using this information we created a pairwise comparison table to assign quantitative weights for each attribute, which is shown in **Table 2**. The final column shows the calculated weights for each attribute.

	Attribute	**Rank**
A	Cost	1
B	Emissions	2
C	Freight throughput	5
D	Jobs	3
E	Noise (dB)	5
F	Traffic	2
G	Aestheticity	6
H	Political support	3
I	On time delivery	5

Table 1. Attribute Ranking

	A	B	C	D	E	F	G	H	I	Total	Weight
A	1	2	5	3	5	2	6	3	5	32	**0.291**
B	0.5	1	2.5	1.5	2.5	1	3	1.5	2.5	16	**0.146**
C	0.2	0.4	1	0.6	1	0.4	1.2	0.6	1	6.4	**0.058**
D	0.333	0.667	1.667	1	1.667	0.667	2	1	1.667	10.667	**0.097**
E	0.2	0.4	1	0.6	1	0.4	1.2	0.6	1	6.4	**0.058**
F	0.5	1	2.5	1.5	2.5	1	3	1.5	2.5	16	**0.146**
G	0.167	0.333	0.833	0.5	0.833	0.333	1	0.5	0.833	5.333	**0.049**
H	0.333	0.667	1.667	1	1.667	0.667	2	1	1.667	10.667	**0.097**
I	0.2	0.4	1	0.6	1	0.4	1.2	0.6	1	6.4	**0.058**
										109.87	**1.000**

Table 2. Pairwise Comparison Table

3.4. Specifications

Because our team was mostly unfamiliar with the issue at hand in the beginning, we intensely researched many topics relevant to our project. Surveys were also conducted to gather opinions on the issue. With the data given to us by GE and Professor Colledge and the information found through research, we compiled a list of specifications. This included all necessary numerical quantities for our project, including costs, emission rates, noise pollution limits, and more.

3.4.1. Cost

Cost is always a huge factor when it comes to implementing changes to a system. This situation is no different. Our project needs to be able to solve the problem that faces Pittsdelphia while incurring as low of costs as possible. **Table 3** below lists all the costs relevant to our project. A 2% yearly inflation rate applies to all recurring costs.

Although we were not given a set budget, discussions with the Pittsburgh planning commission recommended not exceeding 0.01% of the city's GDP per, thus limiting our budget to $13.1 million per year.

Action	**Cost**
Purchasing new tier 4 locomotives	$4 million each
Retrofitting locomotives to tier 3	$850 thousand each
Retrofitting locomotives to tier 4	$1.5 million each
Operating a train	$.0405 per ton per mile

Operating a barge	$.0183 per ton per mile
Operating a truck	$.1654 per ton per mile
Upgrading locomotives to use alternative fuel	$1 million each
Constructing a fueling station	$1 billion

Table 3. Costs

3.4.2. Emissions

Vehicle emissions is obviously a concern. Our solution is required to not only satisfy the complaining residents of Pittsdelphia by reducing smog emissions from freight vehicles, but also to meet EPA's emissions standards. **Table 4** shows the EPA's emission limits for various modes of transportation, while **Table 5** shows the emission rates of those vehicles.

Mode	**PM (g/b.h.p. x hr.)**	**NO_x (g/b.h.p. x hr.)**
Barge	0.1491(ABT)	5.369(ABT)
Rail	0.03	1.3
Truck	0.01(g/mi)	0.2(g/mi)

Table 4. EPA Emission Restrictions

Mode	**PM(kg/ton x mile)**	**NO_x(kg/ton x mile)**
Barge	0.00041	0.00241
Rail	0.0021	0.00831
Truck	0.00286	0.0462

Table 5. Vehicle Emission Rates

3.4.3. Freight Throughput

Our solution is required to maintain the current freight throughput or increase it. Currently, 165,000 tons are carried into the city everyday. The current fleet of consists of 20 trains, so each train carries on average 8,250 tons. The fleet is divided into 15 freight trains and 5

mineral trains, which means roughly 123,750 tons are freight, while the other 41,250 tons are minerals. Table 6 shows how many tons of goods each single vehicle can carry.

Mode	Capacity per unit (tons)
Barge	1,500
Rail	8,250
Truck	26

Table 6. Vehicle Capacities

3.4.4. Jobs

One of the most valued attributes by the Pittsburgh planning commission was how many jobs our solution would create. Table 7 shows how many jobs are created per vehicle used.

Mode	Jobs created per unit
Barge	6
Rail	4
Truck	1

Table 7. Jobs Creation Rates

3.4.5. Noise Pollution

One concern of some residents was the design's impact on surrounding noise. Although we cannot guarantee quietness, especially because vehicles are naturally loud, we will try to keep noise pollution to a minimum. Table 8 shows the average sound power of each mode of transportation.

Mode	Sound power (dB)
Barge	80-85
Rail	90-95
Truck	80-85

Table 8. Vehicle Sound Power Levels

3.4.6. Aestheticity

A very minor concern voiced by some individuals was the solution's aesthetic appeal. By conducting a brief survey, we determined relative values of aestheticity for each mode of transportation, which are shown in Chart 2. Our team decided that although aestheticity was of low importance, we will still try to create a solution that will fulfill a 75% aesthetic rating.

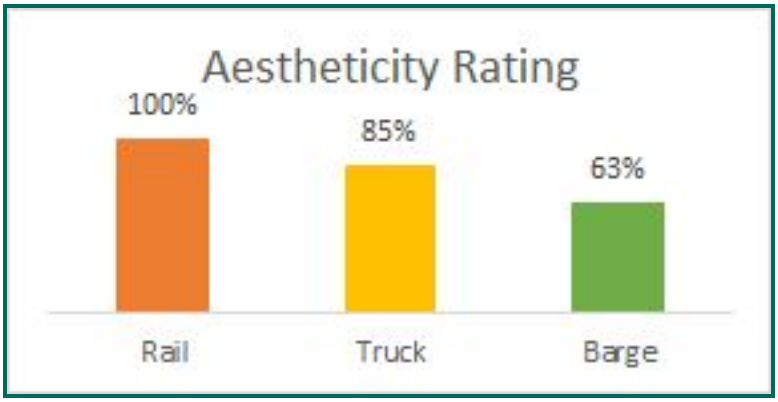

Chart 2. Vehicle Aestheticity Ratings

3.4.7. Political Support

Before we implement any solution, it is important to gain the approval of the the Pittsburgh planning commission. As such, we will only follow through with an idea if it receives at least 4 votes of approval out of the 7 members of the commission.

3.4.8. On-Time Delivery

Many residents stated that on-time delivery is not as important when it comes to bettering our environment. Even so, our team will strive to deliver all goods on time. This means that all goods will be delivered the same day they are shipped. The area of operation is a 500 mile radius around Pittsdelphia. Table 9 shows the average speed of each mode of transportation and each mode's time to traverse the entire 500 mile distance.

Mode	Speed (mph)	500-mile time (hrs)
Barge	11.5	43.47
Rail	50	10
Truck	70	7.14

Table 9. Vehicle Speeds and 500 Mile Times

4. Conceptual Designs

Using the suggestions made by GE, we generated various solution designs, including upgrading the locomotive fleet and employing alternative shipping methods.

4.1. Alternative Fuel Source

When considering the alternative fuel options, we used the investment values that GE provided to us. Upgrading the locomotives costs $1 million each, for a total cost of $20 million. Upgrading the fueling station in Pittsdelphia costs $1 billion. Subsequently, pursuing this solution would cost $1.02 billion upfront. Other operating costs, mainly fuel costs, would increase the total cost by roughly $100 million. We realized that the fueling station alone would push the cost of this project way beyond the expected budget. As a result, we chose alternative fuels that do not require a fueling station, and thus can bypass the $1 billion fueling station cost.

4.1.1. Nuclear

One such alternative fuel that would not require a fueling station is nuclear energy. A nuclear powered locomotive would receive its energy from a miniaturized nuclear fission reactor, using uranium-235 rods as fuel. These fuel rods are able to power the train for several years at a time before being deplenished, so refueling is not a huge concern. Besides, refueling is a simple process of replacing the uranium fuel rods in the reactor and would not require a fueling station. Although acquiring nuclear powered locomotives may carry a high price tag, the benefits gained by their excellent power output are substantial. The emissions from a nuclear powered train would also be significantly lower than that of diesel-electric locomotives.

Unfortunately, there are several major concerns related to operating a nuclear powered locomotive. First, because nuclear powered locomotives are still only a novel concept, with Russia being the only nation to test them, more research and development will probably be required to refine their design. Nuclear reactors output enormous amounts of energy, and even the smallest reactors in use still produce thousands more times energy needed to power a locomotive. In order for this idea to work, a micro reactor must be designed for the sole purpose of powering the locomotive. With this in mind, using nuclear powered locomotives may not actually be a practical solution because Pittsdelphia requires these locomotives as soon as possible.

Additionally, the image a nuclear reactor in motion is quite unsettling. There are huge safety risks involved with having a nuclear reactor on a locomotive. If the locomotive encounters an accident such as a crash or derailing, the consequences may be catastrophic. Even certain weather conditions like blizzards or thunderstorms may cause problems.

Another bizarre yet potential risk is a terrorist attack on the locomotive. There are many people who would like to get their hands on a nuclear reactor, and they aren’t guaranteed to have noble uses for it. With a great distance of railroad tracks spanning through unprotected lands, a

nuclear powered locomotive travelling through would be very susceptible to an attack. In order to prevent such a disaster, it is quite likely that a small military force would have to be stationed on the locomotive. Even so, they may not be able to ensure the locomotive's safety.

Overall, while the advantages in using a nuclear powered locomotive make the idea very attractive, the severe risks involved and the steps needed to be taken to neutralize these risks make the idea seem largely impractical and undesirable.

4.1.2. Solar

In June 2015, Indian Railways announced that it was testing using solar power as a fuel source for its passenger coach trains. Our team decided to take this idea and expand it to freight trains. Solar power offers several major benefits. First, it emits no harmful emissions. Because solar power consumes light energy instead of carbon-based fuel sources, NOx and PM emissions are essentially nullified. Second, the production of electricity from solar energy is a quiet process, meaning noise pollution produced by the trains will be lower. This is in contrast to noise created by the combustion process when using conventional fuel. As a result, the noise generated by solar powered trains will mostly come from the trains running on the tracks. Additionally, the implementation of this idea will not be very complicated. Because the roofs of most locomotive models are bare, the roof is the prime location of installation. The roof also receives the most sunlight, providing another reason for it being the ideal location for solar panels.

However, we also recognize various issues that this idea may face. Our most important concern is the power output supplied by solar power. In order for this solution to be successful, the power output must be high enough not only to power the locomotive and the freight cars, but also to carry the 165,000 tons of freight at an average speed of 50 mph. Additionally, we must consider the effects of environmental conditions and terrain on energy consumption. Conditions that obstruct sunlight, such as foggy or cloudy weather, tunnels, may pose a problem. We must make sure that solar powered locomotives must be able to store enough energy during clear conditions to endure potentially long periods of darkness.

Solar power is a very green solution, and one that has already seen major successes in other fields. Even so, if solar power can't ensure a high and consistent energy output to the locomotive, this idea will have to be scrapped.

4.2. Buying New Tier 4 Trains

One of the simplest answers to the problem we face is just to buy better trains. The primary objectives of our project is to provide a solution that reduces smog emissions and meets EPA emission standards, and buying new locomotives does just that. Because the EPA requires all new locomotives to meet tier 4 standards, buying tier 3 locomotives is not an option, and so the entire fleet of locomotives would have to be replaced with tier 4 locomotives. GE has listed the price a new tier 4 locomotive as $4 million, so replacing the entire fleet of 20 locomotives

would cost a total of $80 million. This value is slightly reduced by salvaging the old locomotives.

It is said that the simple solution is often the best solution. And this case might be no different. However, there are other aspects we must consider, such as this solution's effect on other attributes besides low emissions. If its impact is too negative, then even the simple idea must go.

4.3. Retrofitting Current Trains

A similar idea to buying new trains is upgrading the current ones to perform better. Pittsdelphia's current fleet of locomotives only meets the EPA's tier 2 standards for emissions, but by retrofitting after-treatment systems on them, higher tiers can be reached. Because these locomotives are not new, the EPA allows them to operate at as low as tier 3 standards, so we have the option of upgrading the locomotives to either tier 3 or tier 4. Upgrade and fuel costs differ depending on which tier the locomotive is being upgraded to, so analysis will be done to show if one option is superior.

Another detail of importance is that the current fleet only has a projected lifespan of 10 years from present day. After that decade, the locomotives must be put out of service and new locomotives will be bought to replace them. This means that even if we decided to retrofit the current fleet, we are merely delaying the purchase of tier 4 locomotives. Furthermore, the salvage value of the locomotives at the end of their useful life is much less than that currently. As a result, we suspect that this idea will likely be more expensive than just buying tier 4 locomotives at the start, while not being significantly better in other attributes either.

4.3.1. Tier 3

Retrofitting the locomotives to meet tier 3 standards costs $850 thousand per locomotive, totaling $17 million upfront.

4.3.2. Tier 4

Retrofitting the locomotives to meet tier 4 standards costs $1.5 million per locomotive, totaling $30 million upfront.

4.4. Creating a Multimodal Shipping System

One suggestion that was made by GE was to explore alternative shipping methods, including ground, sea, and air freight shipping. Using the comparison chart provided by GE, shown as **Table 10**, we decided that creating a multimodal shipping system could be a viable solution, as it can utilize the different advantages of each mode of shipping. After further studying the chart and referring to our specifications, we decided to exclude shipping by air as a mode of shipping in our solutions. Although air is the fastest means of shipping, the mediocre

freight capacity and emissions reduction along with the gigantic price tag associated with it deterred us from using it. Additionally, the 500 mile range our project is concerned with does not justify using a long-distance shipping method.

With that parameter determined, we brainstormed several multimodal shipping models that that differed based on the proportion of freight each mode of shipping would carry. The solutions differed in a way such that each one would optimize a certain attribute that was desired. Because GE is a major stakeholder and their locomotives are the main product of focus for this project, we decided that all solutions would have trains carry at least 25% of the total freight. Our brainstorming process produced five solutions.

	Cost	Capacity	Time	Environmental
Truck	+	+	++	
Rail	++	+++	+	++
Sea	+++	++		+++
Air	-		+++	

Table 10. Shipping Mode Comparison

4.4.1. Eco-Friendly

Our eco-friendly model attempted to keep emissions at a minimum. Because barges emit that least amount of NOx and PM out of all modes, the eco-friendly model would maximize their use, having barges carry 75% of the freight, while trains carry the other 25%. Coincidentally, this model also was the most cost-effective solution, having a total cost of approximately $66 million.

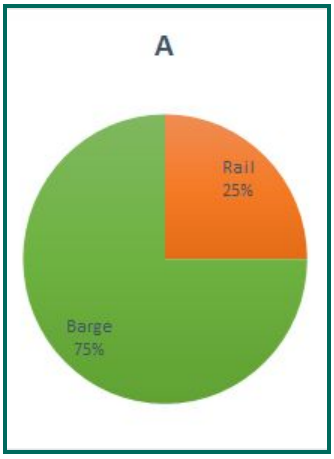

Chart 3. Eco-Friendly

4.4.2. Fast Delivery

Our fast delivery model focused on delivering all freight as quickly as possible to their destination. This solution delivered 40% of the freight with trucks and 60% with trains. Although this solution created the most jobs out of all solutions, it was also the most costly, being the only multimodal solution to exceed the costs of buying tier 4 trains and retrofitting the trains.

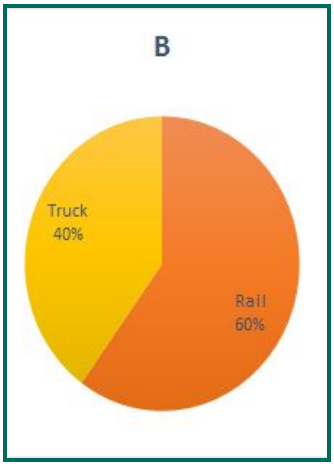

Chart 4. Fast Delivery

4.4.3. Appropriate Shipping Method

The appropriate shipping model looked at the types of freight being carried and assigned them to the most appropriate method of shipping. For example, minerals and raw metals would be shipped on trains, while electronics and forest products would be shipped on trucks. This resulted in 30% of freight being shipped by barge, 17% by truck, and 53% by train.

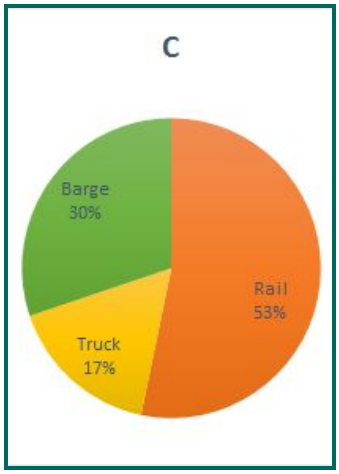

Chart 5. Appropriate Shipping Method

4.4.4. Performance

The performance model attempted to maximize the performance of each mode of shipping by having them only operate within a certain range around the city. We determined that trucks would only operate within 100 miles of Pittsdelphia, trains within 300 miles, and barges within 500 miles. The freight was then distributed proportionally by the area each mode covered. Trucks would carry 14% of the freight, trains 48.5%, and barges 47.5%.

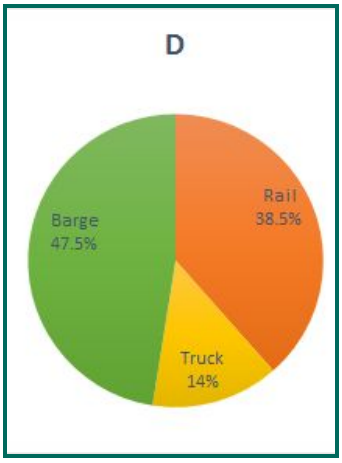

Chart 6. Performance

4.4.5. Public Opinion

Our final solution didn't necessarily optimize a certain attribute but instead was based on the public's opinion. Our team contacted Pittsburgh's planning commission to seek their input on and advice for the project. Driving our public opinion solution from their responses, this solution assigned 65% of the freight to barges, 10% to trucks, and 25% to trains.

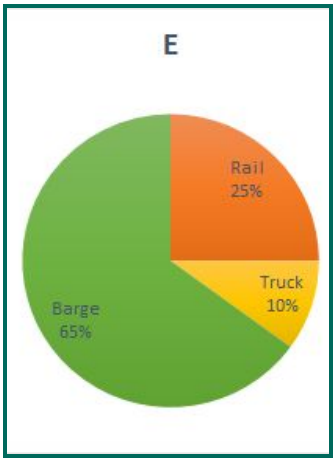

Chart 7. Public Opinion

5. Concept Evaluation

5.1. Replacing/Retrofitting Trains Cost Analysis

Before evaluating our solutions, we first had to determine whether replacing all trains or retrofitting was the better option. Using given data for costs of fuel, retrofitting, and new trains, a graph, shown below, was made comparing the cumulative costs of the three options. **Chart 8** showed that over a twenty year period, buying tier 4 locomotives would cost $122 million, compared to $141 million for retrofitting to tier 3 and $159 million for retrofitting to tier 4. Consequently, we decided that all solution having trains would involve the purchase of new locomotives.

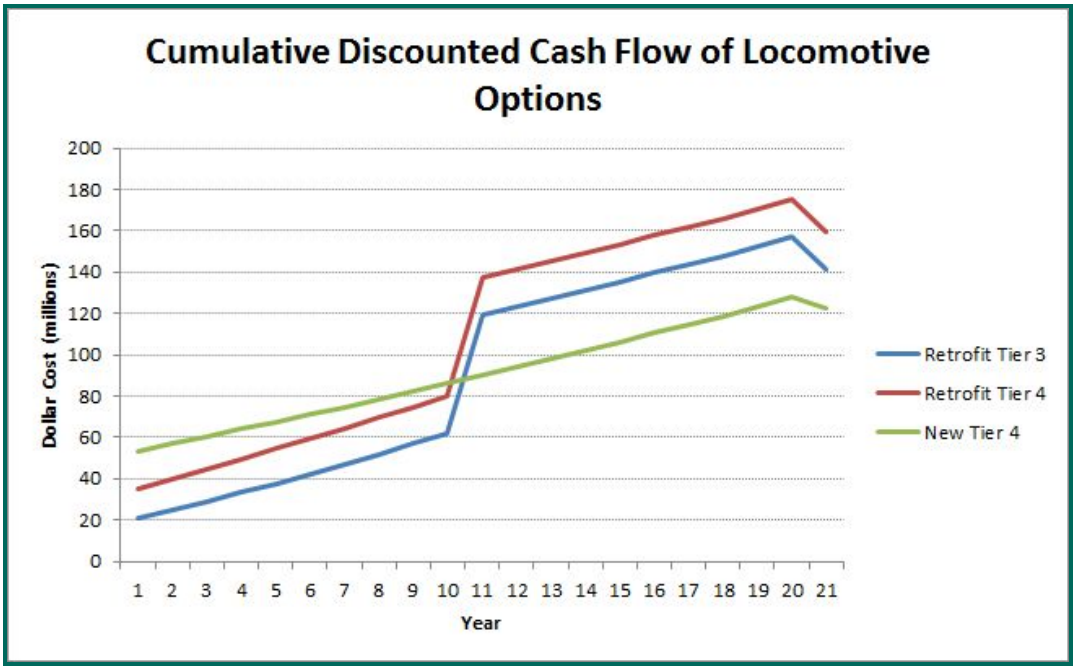

Chart 8. Cumulative Costs of Retrofitting and Replacing Trains

5.2. Concept Selection

Our design evaluation process consisted of a multiple steps. We first performed an initial weeding out of solutions using a concept screening table. Next, we calculated all the necessary values associated to the relevant specifications. Finally, using this data, we selected the best solution using a weighted selection matrix with the weighted attribute values we calculated earlier.

5.2.1. Concept Screening

Table 11 shows the results of our concept screening. Concept screening is the initial step in concept evaluation that determines which designs should be abandoned and which should be continued. Screening the solutions involves assigning a positive, negative, or neutral mark under each attribute for each solution. The marks are then added up, and the solutions which have the most positive totals are the solutions that are kept and developed further.

Attributes	Nuclear	Solar	Buy Tier 4	Upgrade to Tier 3	Upgrade to Tier 4	Mult Ecofriendly	Mult On time	Mult Appropriate	Mult Performance	Mult Public Opinion
Cost	-1	-1	0	-1	-1	1	0	1	1	1
Emissions	1	1	1	-1	-1	1	0	1	1	0
Freight Throughput	1	-1	0	0	0	1	1	1	1	1
Jobs	0	0	1	1	1	1	1	1	1	1
Noise	-1	0	0	-1	-1	0	1	0	1	1
Traffic	0	0	0	0	0	0	-1	-1	1	1
Aesthetics	-1	-1	0	0	0	1	1	0	1	1
Political Support	-1	0	0	0	0	1	1	-1	1	1
On time Delivery	0	-1	1	1	1	1	1	1	1	-1
Total	**-2**	**-3**	**3**	**-1**	**-2**	**7**	**5**	**3**	**9**	**6**
Continue?	no	no	no	no	no	yes	yes	yes	yes	yes

Table 11. Concept Screening

5.2.2. Specification Calculations

Before comparing our solutions, we needed conduct a variety of calculations. These calculations would determine the numerical details of each solution with regard to costs, emissions, noise pollution, jobs created, and aestheticity.

In the following calculations, solution D is used as the basis for all example calculations.

5.2.2.1. Cost

<u>Formula:</u> operating cost * unit capacity * distance * # of vehicles

<u>Example:</u> $\frac{\$.0405}{ton*mile} * 8250\ tons * 500\ miles * 8\ trains = \$1,336,500/$ year for operating trains

5.2.2.2. Emissions

<u>Formula (applies for both NOx and PM):</u> emission rate * total weight * distance * percentage

<u>Example:</u> $\frac{0.00831kg}{ton*mile} * 165000\ tons * 500\ miles * 38.5\% = 263,652.27\ kg$ NOx emitted per day

5.2.2.3. Noise Pollution

Formula: sum:(percentage * sound power)

Example: $38.5\% * 92.5\ dB + 47.5\% * 82.5\ dB + 14\% * 82.5\ dB = 86.35\ dB$

5.2.2.4. Jobs

Formula: sum:(job creation rate * # of vehicles)

Example: $4 * 8\ trains + 6 * 52\ barges + 1 * 888\ trucks \approx 1,233$ jobs created

5.2.2.5. Aestheticity

Formula: sum:(percentage * aestheticity rating)

Example: $47.5\%\ barge\ * 63 + 38.5\%\ train\ * 100 + 14\%\ truck * 85 = 80.325$ aestheticity rating

5.2.3. Specification Analysis

Once all our core calculations were complete, we could then compare the solutions. The specifications of each solution were analyzed by graphing their values and comparing them with each other solution.

5.2.3.1. Cost

Chart 9 graphs the yearly cost of each solution over a span of two decades while taking inflation rates into account. This graph clearly shows that solution B cost significantly more than any of the other solutions.

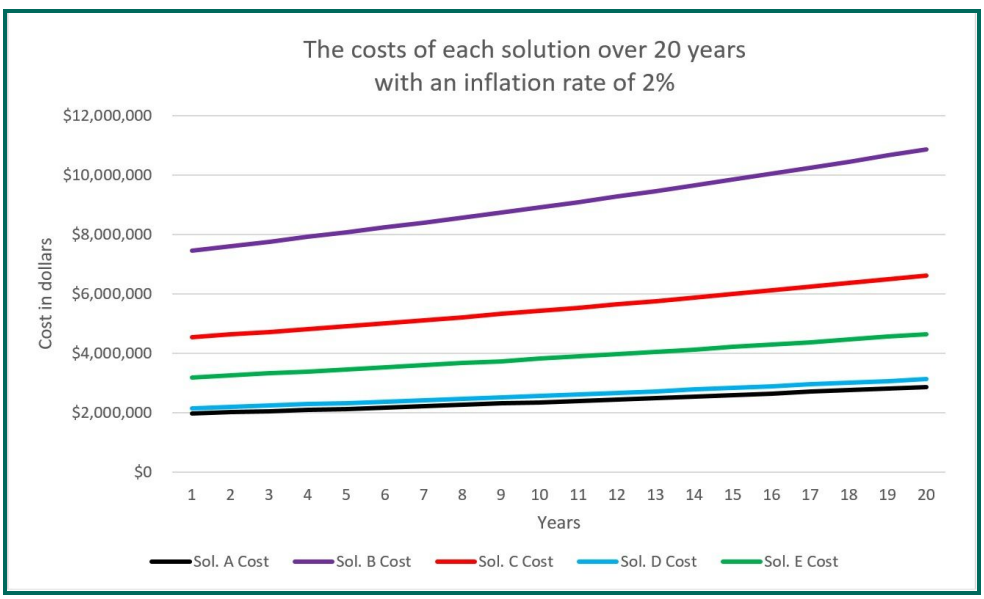

Chart 9. Yearly Costs Over 20 Years

Chart 10 compares the total costs of each solution, found by taking the area under the curve for each solution from **Chart 9**, with each other as well as with replacing and retrofitting

all locomotives. This chart shows that most of the multimodal solutions were less costly than just replacing or retrofitting the fleet. Solutions A and D boast the lowest costs at $66 million and $82 million, respectively.

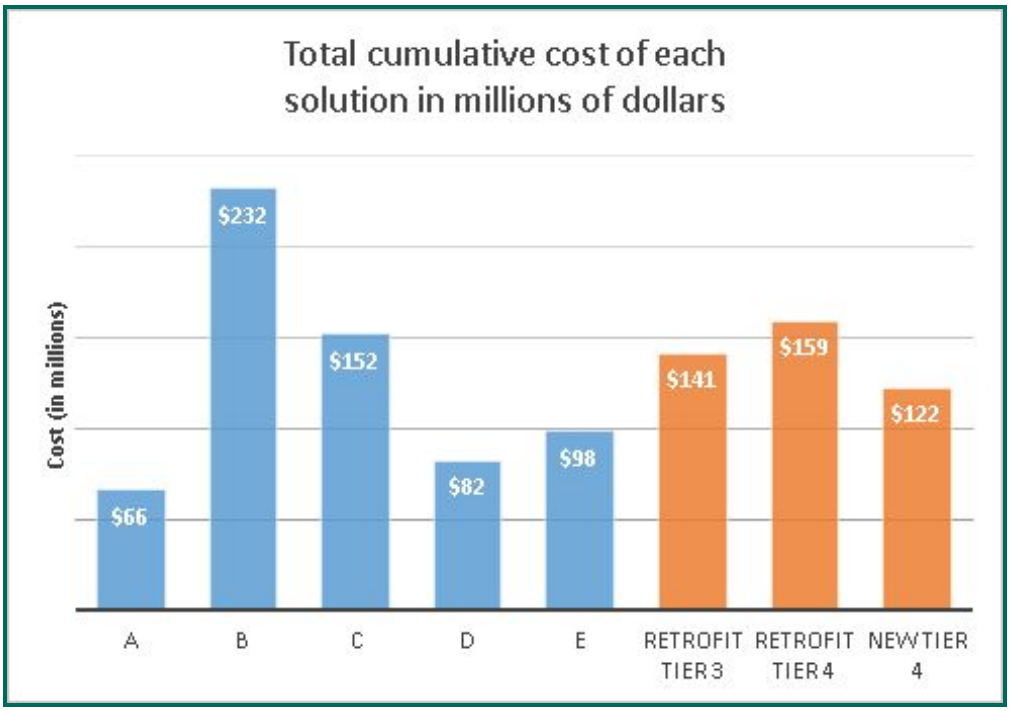

Chart 10. Cumulative Costs of Solutions

5.2.3.2. Emissions

Chart 11 and **Chart 12** show the NOx and PM emissions, respectively. These graphs show that solutions C and E creates the most NOx emissions, while solution B and C creates the most PM emissions. Overall, solution C is the least desirable when it comes to reducing emissions.

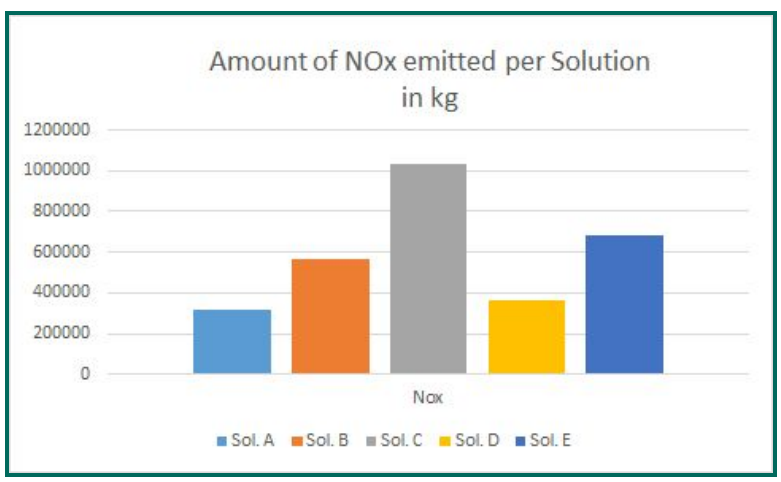

Chart 11. NOx Emissions Analysis

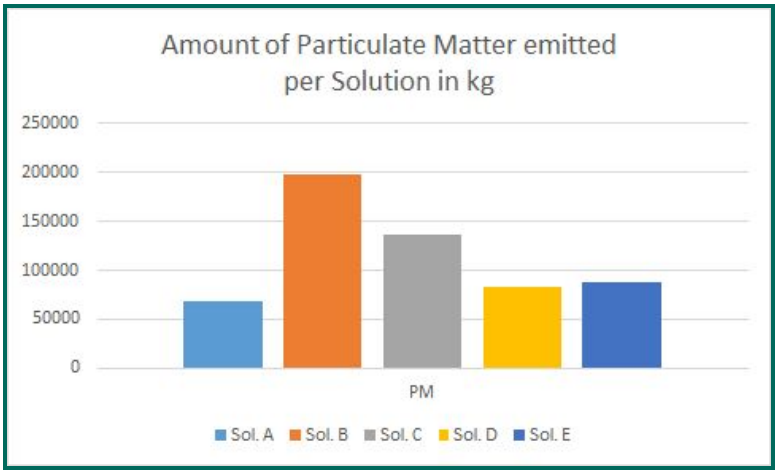

Chart 12. PM Emissions Analysis

5.2.3.3. Noise Pollution

Chart 13 compares the noise pollution caused by each solution. Overall, these values are extremely close, with solutions A and E barely coming out on top at an average of 85 dB each.

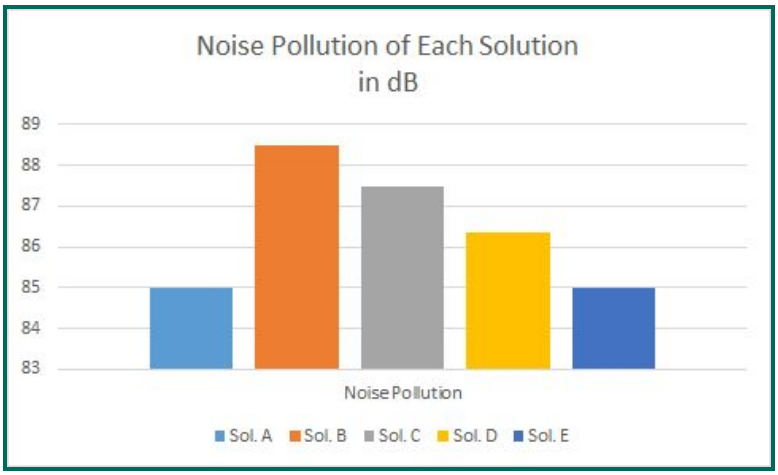

Chart 13. Noise Pollution Analysis

5.2.3.4. Jobs

Chart 14 compares the jobs created by each solution. Solution B greatly surpasses all other solutions in this aspect, creating a total of 2,587 jobs.

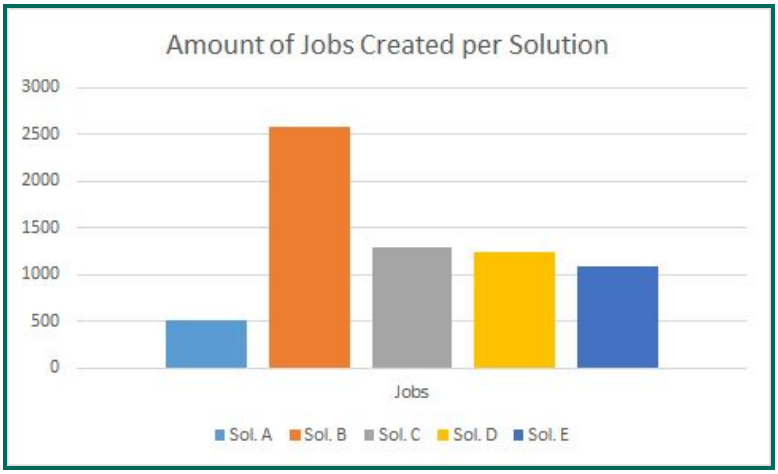

Chart 14. Jobs Analysis

5.2.4. Weighted Selection Matrix

Using the information obtained from the specification analyses, we used a weighted selection matrix to score each solution and determine the best solution. Table 12 provides attribute weights as a reference, while Table 13 shows the results of the concept scoring. We determined that solution D was the best solution, as it balanced the merits of each specification very well.

	Attribute	Rank	Weight
A	Cost	1	0.291
B	Emissions	2	0.146
C	Freight throughput	5	0.058
D	Jobs	3	0.097
E	Noise (db)	5	0.058
F	Traffic	2	0.146
G	Aestheticity	6	0.049
H	Political support	3	0.097
I	On time delivery	5	0.058

Table 12. Attribute Ranking and Weights

Concept Scoring					
Factors x Weight	Type of System				
	25% R 75% B	40% T 60 % R	53% R 16.5 T 30% B	38.5% R 14% T 47.5% B	10% R 25% R 65% B
	A	B	C	D	E
A (x 0.3)	5	0	1	4	2
B (x 0.14)	5	2	0	4	2
C (x 0.06)	0	2	3	5	0
D (x 0.099)	0	5	4	4	1
E (x 0.06)	5	0	1	4	5
F (0.14)	4	1	3	4	4
G (x 0.099)	1	4	2	2	2
H (x 0.099)	1	5	1	3	4
I (x 0.06)	0	5	3	4	2
Total	3.208	2.026	1.733	3.891	2.453

Table 12. Weighted Selection Matrix

6. Detailed Design

Figure 1 shows the systems diagram of our final solution. In summary, our solution to improving the shipping industry of Pittsdelphia is a multimodal system that uses trains, barges, and trucks in tandem to deliver freight to the city. Our design optimizes the performance of each mode of transportation by having trucks operate only within 100 miles of the city, barges within 300 miles, and trains within 500 miles. The freight throughput of 165,000 tons is maintained, while 1,233 jobs are created to operate the vehicles. The solution requires a $32 million payment in advance to purchase the new tier 4 trains and further requires roughly $2 million per year in operating costs for the vehicles. Over 20 years, the total cost of our solution is approximately $82 million. Our design well exceeds the EPA's tier 4 emission standards by only producing just over 400 thousand kilograms in NOx and PM emissions every day.

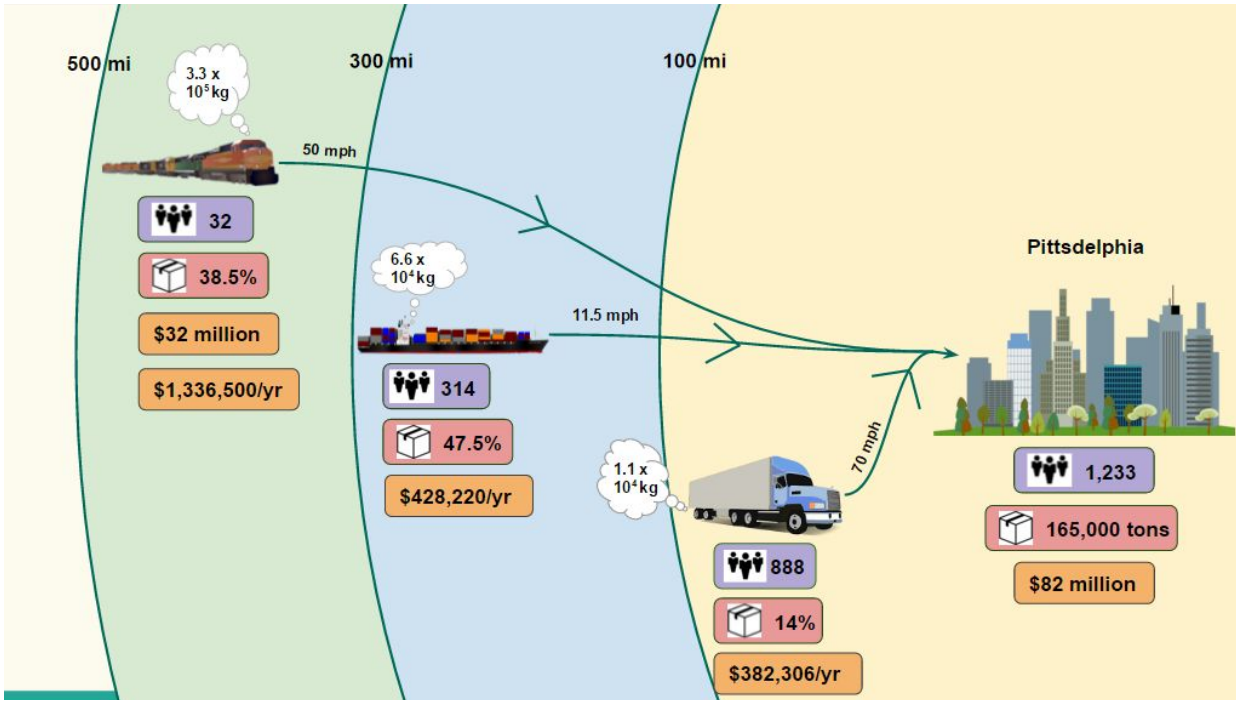

Figure 1. Systems Diagram: Solution D

7. Conclusion

For the second design project, we were approached by General Electric with the task of updating the freight shipping industry of the fictional city of Pittsdelphia. Needing to adhere to the Environmental Protection Agency's advancing emission standards as well as to placate the city's residents complaining about smog, our team strove to create a new freight shipping model for the city.

This 3-month project began with identifying the stakeholders associated with the project and determining the most important attributes required from our final design. We explored several potential options, including buying new trains, retrofitting current trains, using alternative fuels, and creating multimodal shipping systems. Through further analyses, we determined that a multimodal shipping system which used new tier 4 locomotives is the most effective and desirable option.

Specifically, our best multimodal system assigns each mode of shipping to operate within its optimal range, with trucks shipping everything within 100 miles of Pittsdelphia, barges shipping everything within 300 miles, and trains shipping everything within 500 miles. Costing only $82 million over 20 years, this solution greatly reduces NOx and PM emissions caused by freight vehicles, which will alleviate many of the city residents' complaints.

Overall, not only will our solution greatly improve Pittsdelphia's freight shipping industry, it will also create a greener environment.

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