PennState College of Engineering | ENGINEERING DESIGN, TECHNOLOGY, AND PROFESSIONAL PROGRAMS

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GE Transportation

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SECTION 1 EXECUTIVE SUMMARY

Pittsburgh is looking for the proposal of a cost-efficient freight shipping system that decreases smog and meets EPA requirements, while maintaining or increasing freight capacity into and out of this important port city. The options of using locomotives, trucking, or barges are possibilities for the proposal.

SECTION 2 INTRODUCTION

2.1 Project Objectives. Pittsburgh is looking for the design of a cost-effective solution for its freight that reduces smog and meets EPA requirements, while maintaining or increasing freight capacity into and out of this important port city, which should be both cost efficient, safe for the environment, and safe for society as well.

2.2 Project Background Every day into and out of the port city of Pittsburgh, approximately 165,000 tons of freight or minerals (coal, etc.) per day travel via rail. Smog from locomotive emissions is a key complaint of city residents. Smog is generated from engine-emitted NOx. Tier 2 locomotives used to haul freight are approaching age for overhaul, at which time investments will be required to meet EPA Tier 3 (or higher) requirements.

Suggestions have been made to address locomotive emissions (i.e., smog) by

1) Upgrade the locomotive fleet to meet more recent emissions guidelines set by the EPA. A few options may exist to meet the new guidelines:

- Sell existing fleet and purchase new locomotives
- Upgrade fleet with exhaust after-treatment hardware
- Utilize alternate fuels (Biodiesel, CNG, LNG, etc.), which may produce less NOx

2) Alternate freight shipping methods:

- By sea
- By air
- By ground, i.e., trucking

2.3 Project Sponsor Background. GE Transportation, a unit of GE (NYSE: GE), solves the world's toughest transportation challenges. GE Transportation builds equipment that moves the rail, mining, and marine industries. GE's fuel-efficient and lower-emissions freight and passenger locomotives; diesel engines for rail; marine and stationary power applications; signaling and software solutions; drive systems for mining trucks; and value-added services help customers grow. GE Transportation is headquartered in Chicago, IL, and employs approximately 13,000 employees worldwide.

2.4 Project Description. Each design team should research and evaluate the suggestions made for fleet upgrade or alternate shipping methods. For upgrades, consider physical

constraints of new hardware, as well as fuel storage requirements. Provide your recommendations, commenting on impact to:

1) Emissions/Regulatory requirements

2) Costs: fuel, infrastructure, etc.

3) Freight throughput/capacity

4) Public opinion

5) On time delivery

2.5 Project Freight Requirements. The freight requirements are at least one full size locomotive plus many rail cars. The locomotive will be providing the power for all the rail cars. They're could also legally be more than one locomotive powering the rail cars depending on how large the load is, up to three locomotives could be used. Placement of locomotives throughout the train maximizes performance and improves efficiency.

2.6 Transportation Mode Comparisons.
Locomotives are very powerful and very efficient. One GE locomotive has the power of 80 full size SUV's alone. New locomotives can be up to ten times more efficient then diesel trucks for shipping goods. These incredibly efficient locomotives have very little friction compared to the large tractor-trailers. Trucks of course come at a cheaper price and are significantly easier for them to get from point A to point B. Barges are also an option which can hold vast amounts of goods. They are also an extremely efficient way to ship goods, but of course you need water. Each three means of transportation have their pros and cons.

SECTION 3 TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY

3.1 Introduction.

The Pennsylvania Infrastructure Report Card showed that in 2014, the infrastructure of PA has room for improvement. Our highest grade was a B in Freight Rail, while our lowest was a D-, in wastewater and roads. The average grade for the state's infrastructure is a C-. It is critical that we focus on improving in areas that need attention, and maintaining what is currently in good quality. The information provided by the report card shows that using freight railways will likely be the most efficient method of transportation.

3.2 Pennsylvania Roads and Bridges.

In 2014, Pennsylvania received a D+ in bridges, and a D- in roads. These are both very important areas in our infrastructure and in our daily lives, so improving these is crucial. 8.8 million Pennsylvania drivers travel nearly 100 billion miles every year. However, 44% of Pennsylvania's roads were rated as fair or poor in 2014. Additionally, traffic is a big concern. 182 hours and 86 gallons of fuel are wasted every year by drivers sitting in traffic in urban areas. This is equivalent to a loss of $3.7 billion. Given this information, it is apparent that Pennsylvania's road system needs a serious upgrade.

Pennsylvania's bridges also require a good deal of attention. Of Pennsylvania's 22,660 bridges, 23% are structurally deficient. That's about 5,200 in total. This is the highest percentage in the country. On top of that, 19% of PA's bridges are functionally obsolete. A major overhaul is also necessary for the bridges of Pennsylvania.

3.3 Pennsylvania Inland Water Ways.

Pennsylvania's inland waterways are not in great shape, receiving a grade of D+. Only 18% of PA's locks, and zero PA's dams have a satisfactory rating due to a lack of maintenance. Shipping delays at degraded facilities are common and are having negative effects on the economy. Further damage to our inland waterways will have negative effects on the industries that rely on waterway transportation.

3.4 Pennsylvania Freight Rail System.

Pennsylvania's 57 freight railways, spanning 5127 miles, is the 4th largest rail network in the country. By 2035, these railways are expected to carry 246 million tons of freight throughout the state; a 22% increase from the percentage in 2007. Railroad traffic is steadily increasing over time, and railroad condition must be properly maintained to handle this growth of production.

SECTION 4 STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

4.1 Cargo Capacity.

- One barge has the capacity of 1,500 tons of freight, which is equal to 52,500 bushels, or 453,600 gallons
- One 15 barge tow has the capacity of 22,500 tons of freight, which is equal to 787,500 bushels or 6,804,000 gallons
- One bulk railroad car (jumbo hopper) has a capacity of 100 tons of freight, which is equal to 3,500 bushels or 30,240 gallons
- One boxcar has a capacity of about 95 tons, which is approximately 3,325 bushels or 28,728 gallons
- One large semi has a capacity of 26 tons, which is equal to 910 bushels or 7,865 gallons

4.2 Equivalent Units.

- One barge is equivalent to 15 jumbo hopper cars, which is equivalent to 58 large semi-trucks
- One 15 barge tow is equivalent to 2.25 100 car unit trains, which is equivalent to 870 large semi trucks

4.3 Equivalent Lengths.

- One 15 barge tow has a length of ¼ mile
- 2.25 100 car train units (the same as one 15 barge tow) has a length of 2.75 miles
- 870 large semi-trucks (the same as one 15 barge tow) has a length of 11.5 miles (with the trucks bumper-to-bumper)

See **figure 4** for more details on 4.1 and 4.2.

SECTION 5 TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)

5.1 Trucks. After surveying and collecting data from 30,083 trucks and 85,000 trailers that drove close to 3.5 billion miles, the transportation costs were quite expensive. The average cost per mile was $1.676. The average cost per hour was $65.68. The average maintenance was 13.8 cents per mile. 16.3 cents was the truck lease average cost. Tire costs were 4.5 cents per mile and tolls 1.1 cents per mile. Hourly wages for drivers was on average $17.60. These are some of the highest prices the ATRI has seen and is a competitive market.

5.2 Barges. 23,000 barges operate in US waterways. To move one ton of freight one mile it costs 97 cents. They work on a dollar per ton basis so depending shipment, high cost to operate. There are $150 demurrage rate and $650 per each stop-off. But for the most part this is the most cost effective with burning less fuel/coal, more can be shipped, and not much can go wrong.

5.3 Railroad. There is an immense amount of trains in the US. To run a train there is not many costs. With what info I could find, shipping bulk through trains is cheap at only 3 cents per ton-kilometer. It would be 10 cents per passenger-kilometer and on a relatively dense freight oriented railroads can average 2 cents per ton-kilometer. The train method seems the most effective because of such low costs.

5.4 Most Economical Transportation Solution. After analyzing the railroad, barges, and trucks, the least expensive way of transportation would be the railroad at fewer than 10 cents per ton-kilometer. The barge would be the next cheapest at 97 cents a mile (without other costs) and then trucks with $1.67 per mile. The most economical would be the railroad because of coast and because it can carry the most cargo too.

Mode of Transportation	Costs	Tons of Cargo	Bushels of Cargo
One Barge	$0.97 per mile	1,500 tons	52,500 bushels
100-car Train Unit	$0.10 per ton-kilometer	10,000 tons	350,000 bushels
Large Semi	$1.67 per mile	26 tons	910 bushels

5.5 Concept of Operations (ConOps).

a. General Description. The proposed transportation system would be to use railroad and upgrade the trains to tier 4. Because of the low cost of operation and maximum amount of cargo and humans shipped it would be the best method. With the new trains it should be also better for the environment. 15 locomotives for our specific operation would be optimal, each with 50 cargo trains. The transportation system would operate at a port to start with then move up a existing railway. If we sell old trains, get new ones and opereate the 15, they will be eficient and cheap

b. Operational Policies and Constraints. The hours of operation should be 1- 3 hours per locomotive and depending on what they are carrying with only one locomotive operator. One person is sufficeinet enough to be in the train if its cargo. I would staff a couple people at a station to make sure everything goes to plan and oversee everything. Equipment restraints would be on emissions and make evreything efficient. Also no extra things. The train will be max capacity all the time with all space accounted for for maximum yeild.

c. Performance characteristics. The locomotives should go about 250 mph with 50 cargo trains behind it. On average trains can be very relaible with being late at most 2-5 minutes and only breaking down in seveare weather and freak accidents. Security would be for cargo to not let any other people on and have cameras and security at stops. A checklist of what comes on and off the train will also be helpful and maximize efficency. Safetly is a top priority so the railway will be fenced and conductors will only take certain amount of shifts so they are always rested.

d. Operational Impacts. The transportation system impacts on the local population by provided a possible transportation for them. It will make jobs and create travel and flow of commerce and goods. Plus it will be very good for the environment. If we use the upgraded tier 4 trains, emissions will be cut by close to 70%. This is the future of railroad and trasportation.

e. Continuity of Operations. If there was an event of catastrophic, emergency condition, or extreme weather all employees will be trained. It will be a priority to if need be stop train until its safe to continue. If it is possible to get the train to its stop then that must be done. We want out employees safe and will have teams come get them if that has to happen. Human life is first then its about the cargo and trains.

SECTION 6 EPA DIESEL EMISSION STANDARDS

6.1 Background.

In 2008, the EPA made drastic steps to reduce emissions from all types of diesel locomotives, including switch, line-haul, and passenger rail. They came up wit a three-part program. The goal is to cut PM emissions from all of these engines by 90 percent and NOx emissions by 80 percent. This is a huge leap to help protect the environment. This will all be applied to engines made in 2015 and after due to new high efficiently technology. The EPA regulatory standards histories for tier 0-2 were adopted on December 17, 1997. It applied to every locomotive manufactured from 1973 and on. The standards are met through engine design methods and without the use of exhaust gas after treatment. The EPA regulatory standards histories for tier 3-4 were signed on March 14, 2008. This introduced more stringent emission requirements. Tier 3 standards were engine design methods and these became effective in 2011. Tier 4 standards were to require exhaust gas after treatment technologies, and in 2015. It would also have many modifications to the original standards for tier 0-2 locomotives.

6.2 Tier 0-2 Standards.

Table 1 Tier 0-2 Locomotive Emission Standards, g/bhp·hr

Duty Cycle	HC*	CO	NOx	PM
Tier 0 (1973 - 2001)				
Line-haul	1.0	5.0	9.5	0.60
Switch	2.1	8.0	14.0	0.72
Tier 1 (2002 - 2004)				
Line-haul	0.55	2.2	7.4	0.45
Switch	1.2	2.5	11.0	0.54
Tier 2 (2005 and later)				
Line-haul	0.3	1.5	5.5	0.20
Switch	0.6	2.4	8.1	0.24
Non-Regulated Locomotives (1997 estimates)				
Line-haul	0.5	1.5	13.5	0.34
Switch	1.1	2.4	19.8	0.41
* HC standard is in the form of THC for diesel engines				

Table 2 Locomotive Smoke Standards, % opacity (normalized)

	Steady-state	30-sec peak	3-sec peak
Tier 0	30	40	50
Tier 1	25	40	50
Tier 2 and later	20	40	50

6.3 Tier 3-4 Standards.

Table 3 Line-Haul Locomotive Emission Standards, g/bhp·hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0a	1973-1992c	2010d	1.00	5.0	8.0	0.22
Tier 1a	1993c-2004	2010d	0.55	2.2	7.4	0.22
Tier 2a	2005-2011	2010d	0.30	1.5	5.5	0.10e
Tier 3b	2012-2014	2012	0.30	1.5	5.5	0.10
Tier 4	2015 or later	2015	0.14f	1.5	1.3f	0.03

a - Tier 0-2 line-haul locomotives must also meet switch standards of the same tier.
b - Tier 3 line-haul locomotives must also meet Tier 2 switch standards.
c - 1993-2001 locomotive that were not equipped with an intake air coolant system are subject to Tier 0 rather than Tier 1 standards.
d - As early as 2008 if approved engine upgrade kits become available.
e - 0.20 g/bhp-hr until January 1, 2013 (with some exceptions).
f - Manufacturers may elect to meet a combined NOx+HC standard of 1.4 g/bhp-hr.

Table 4 Switch Locomotive Emission Standards, g/bhp·hr

Tier	MY	Date	HC	CO	NOx	PM
Tier 0	1973-2001	2010b	2.10	8.0	11.8	0.26
Tier 1a	2002-2004	2010b	1.20	2.5	11.0	0.26
Tier 2a	2005-2010	2010b	0.60	2.4	8.1	0.13c
Tier 3	2011-2014	2011	0.60	2.4	5.0	0.10
Tier 4	2015 or later	2015	0.14d	2.4	1.3d	0.03

a - Tier 1-2 switch locomotives must also meet line-haul standards of the same tier.
b - As early as 2008 if approved engine upgrade kits become available.
c - 0.24 g/bhp-hr until January 1, 2013 (with some exceptions).
d - Manufacturers may elect to meet a combined NOx+HC standard of 1.3 g/bhp-hr.

SECTION 7 DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

7.1 Diesel Emission Chemistry.

a. NOx. Some of the pollutants of diesel emissions are caused by a reaction involving nitrogen and oxygen. Nitrogen monoxide and nitrogen dioxide is formed when air is heated. The quantity of these compounds grows exponentially with temperature. Nitrogen monoxide is certainly the more dominant of the two nitrogen-oxygen pollutants as nitrogen dioxide requires extremely high temperatures and they decompose quickly.

b. Particulate Matter (PM). This pollutant has no specific chemical formula. Particular matter is considered whatever is collected on the test filter. This includes, but is not limited to, soot, combustion byproduct, metal, ash and other organic matter.

c. CO_2. Carbon dioxide is a product of the combustion reaction occurring as fuel burns. The amount of CO_2 produced is directly proportional to fuel consumption. Thus, reducing fuel consumption can limit the amount of carbon dioxide released into the atmosphere.

d. Hydrocarbons (HC). Fuels are made up of hydrocarbons. When a fuel does not burn or burn fully hydrocarbons end up being a pollutant instead of a fuel. As a pollutant, hydrocarbons react with nitrogen dioxide in the presence of sunlight to make ozone. At ground level, ozone causes smog and causes respiratory problems.

7.2 Diesel Emission Reduction Strategies. There are several approaches to reducing the emissions of diesel engines. Currently the city contains tier two locomotives. It would be most economical to simply upgrade the locomotives to tier three. This would reduce NO_x and PM emissions by 26% and 50%, respectively. This would cost $750,000 per locomotive. There is also an option of buying tier three locomotives for three million dollars for the same emission results with a new set of machines. For the tier three locomotives, after-treatment will cost $100,000. In addition, purchasing tier four locomotives would reduce emissions (compared to tier three) of NO_x and PM by 76% and 70% respectively. These tier four locomotives would cost four million dollars each.

7.3 Alternate Fuels. Alternative fueling is becoming more and more feasible as time goes on. However, reaching the energy output per a given volume of gas or diesel is no small task. Therefore, biodiesel and liquid natural gas are the most viable alternative options at this point in time. Biodiesel is $2.93/gallon – the same price as diesel. Biodiesel has slightly less energy per gallon. It has 99% of the energy of one gallon of diesel. This may not sound like much but could end up being very impactful over time. Compressed

natural gas may be the best alternative option as it is priced at $2.12 per GGE (gallon of gas equivalent). Unlike diesel, biodiesel is renewable. Compressed natural gas even can come from a renewable resource (biogas) as well as the large reserves of natural gas in the United States. In order to convert each locomotive to an alternative fuel, it would cost one million dollars each. In addition, the fueling station would be another one billion dollars.

7.4 Human Health Issues. Both short and long term exposure to diesel emissions have been shown to cause potential health risks. In regards to the short-term effects, diesel emissions can cause respiratory irritation and cause allergy-induced reactions like asthma. In long-term effects, even low amounts of diesel emissions can cause inflammation and unintended changes to the lungs. In addition, low amounts of exposure over a long period of time can produce effects that have carcinogenic properties. It is hard to determine in what capacity because it is difficult to determine average consumption of diesel emissions for people.

SECTION 8 LOCOMOTIVE FLEET UPGRADE

8.1 Alternatives.

i. There are currently 50 locomotives in the fleet. One option is to sell these locomotives and purchase new ones. Each new locomotive would be three million dollars each (for tier three). If it is decided that tier four locomotives are preferred, it would cost four million dollars per locomotive. While tier three is less expensive, tier four releases much less NO_x and PM pollutants.

ii. Another option is to upgrade the current fleet. At the moment, all the locomotives are tier two but can be upgraded for $750,000 each with an additional one hundred thousand dollars each for after treatment. This is the most affordable option but perhaps not the most beneficial, especially if older locomotives are upgraded.

iii. The use of alternative fuels will be the most effective in reducing pollution, particularly NO_x and PM pollution. Compressed natural gas is the most affordable, followed by biodiesel. While the reduction in pollution is a plus, this is the most expensive option as each upgraded locomotive would cost one million dollars while the fueling station would cost one billion dollars.

8.2 Existing Fleet Make-Up. {NOTE: Assume: (i) fleet consists of the following locomotives and (ii) locomotives are rebuilt at 750,000 mile intervals.}

No. of Existing Locomotives	Locomotive Group Designation	Assumed Existing Locomotive Mileage Range	Assumed Existing Diesel Type
10	A	<150,000	Tier 2
10	B	>150,000 and <300,000	Tier 2
10	C	>300,000 and <450,000	Tier 2
10	D	>450,000 and < 600,000	Tier 2
10	E	>600,000 and <750,000	Tier 2

8.3 Investment Data.

Fleet Upgrade Solutions	Details	Costs
Diesel Locomotive Upgrade	Upgrades a tier 2 locomotive to tier 3	Approx. $750,000 per locomotive
New Locomotives	Buy new locomotives (tier 2 or 3)	Tier 3: $3million per locomotive Tier 4: $4million per locomotive
Alternative Fuel	Uses something other than diesel for fuel	-$1million upgrade per locomotive -$1billion fueling station

8.4 Upgrade Strategy. In order to be most cost effective while paying attention to responsibilities to the environment, a creative combination of the options were used to upgrade the locomotive fleet. For fleet groups A and B, the locomotives were upgraded to level three for $750,000 each. Groups C, D, and E were all sold. Thirty tier 4 locomotives were purchased to replace the ten locomotives in each group. While upgrading locomotives to use alternative fuels would have been ideal for the environment, the cost would be too great as major infrastructure changes would be necessary such as the 1 billion dollar fueling station required.

8.5 Upgrade Schedule and Costs.

Group A: 10 locomotives * $750,000 (cost of upgrade) = $7,500,000

Group B: 10 locomotives * $750,000 (cost of upgrade) = $7,500,000

Group C: 10 locomotives *$4,000,000 (tier 4 locomotive) = $40,000,000

Group D: 10 locomotives *$4,000,000 (tier 4 locomotive) = $40,000,000

Group E: 10 locomotives *$4,000,000 (tier 4 locomotive) = $40,000,000

Total cost: $7,500,000 + $7,500,000 + 40,000,000 + 40,000,000 + 40,000,000 = **$135,000,000***

*This cost will be reduced as revenue is generated by the sale of the locomotives in groups C, D, and E.

SECTION 9 SUMMARY

The city of Pittsburgh needed a plan in which it could continue to meet its transportation demands while dealing with smog issues and meeting EPA requirements. Using creativity and the provided data, a plan in order to upgrade the locomotives in Pittsburgh has been devised. With the implementation of this plan, it appears both business and the environment will benefit greatly.

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Figure 1. Typical Diesel Truck and Trailer.

Figure 2. Typical Diesel-Electric locomotive.

Figure 3. Typical Inland Water Ways Barge and Tug.

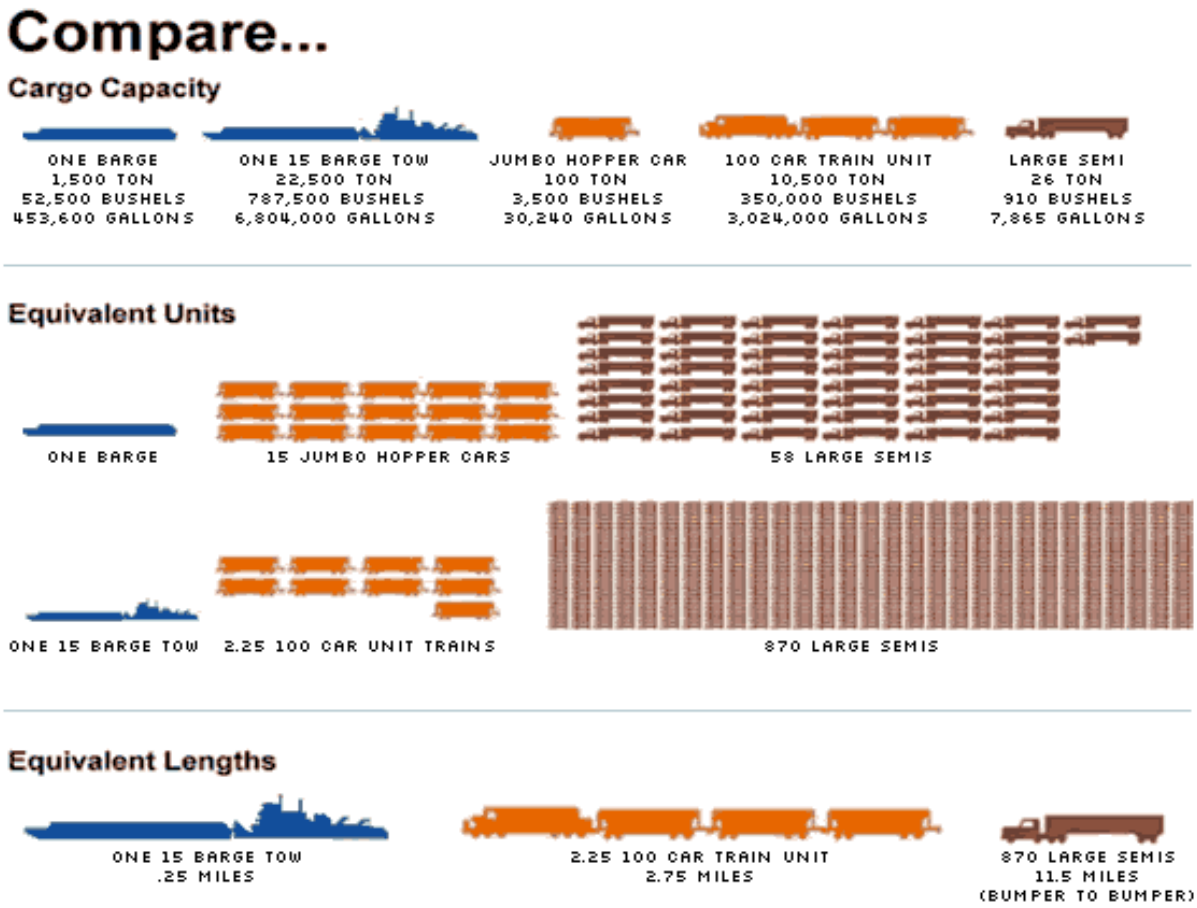

Figure 4. Cargo Capacity