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Freight, Fuel, & Emissions

GE Transportation

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Section 001

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Greg Peter
Courtney Wengert
Stefan Bruder
Jacob Wagner

Submitted to:
Professor Berezniak

College of Engineering
School of Engineering Design, Technology and Professional Programs
Penn State University

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Penn State University

- **Dean, College of Engineering**
  Amr S. Elnashai, FREng The Harold and Inge Marcus Dean of Engineering

- **Department Head, SEDTAPP**
  Sven Bilén, PE, Head, School of Engineering Design, Technology, and Professional Programs

- **Course Instructor**
  John Berezniak, PE, Instructor, Engineering Design

- **Laboratory Assistants**
  Sean Fitzpatrick, Mechanical Engineering

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Section 1 Executive Summary

General Electric (GE) is a company that is always modernizing technology to keep up with the every changing world, as well as the people who live in it. So what do you do when the people stop rooting for you? This is a case that GE is facing in Pittsburgh, PA right now. The people don't like the all of the pollution given off by locomotives in the area, so how can they fix this problem? Perhaps part of the reason that the locomotives are creating so much pollution is the fact that they are out of date. GE needs to upgrade their fleet from Tier 2 to Tier 3 by the end of the year. GE has several options on how to upgrade their fleet, if they even chose to upgrade it at all. The company could go for a new method of transportation all together. This report will go over all of the information one would need to know for how to make these improvements/decisions and also an opinion from what our design team thinks is best.

SECTION 2 INTRODUCTION

2.1 Project Objectives. The objective of this project is to find a cost effective solution for Pittsburgh's freight system. The design should maintain/increase freight capacity into and out of the city while reducing smog and sticking to EPA requirements.

2.2 Project Background. Pittsburgh is a very important port city, it carries 165,000 tons of freight or minerals per day via rail road. This is a great achievement for the port from a business aspect, however the city residents don't appreciate the effects of all the railroad usage. Smog is produced from engine emitted NOx, and is the main reason for the complaints from the people. Investments will soon be required to meet EPA Tier 3 requirements when the Tier 2 locomotives finally hit their overhaul age. GE really only has 2 options for when this time comes, upgrading their locomotive fleet (to meet more recent emission guidelines set by the EPA) or use alternative shipping methods. If they choose to upgrade their fleet some options are to utilize alternate fuels to reduce the NOx emitted, upgrade the exhaust after-treatment hardware or to buy a whole new locomotive line. If they want to forget locomotives all together, they could look into shipping by sea, air or standard ground shipping.

2.3 Project Sponsor Background. GE Transportation, a unit of GE (NYSE:GE) finds solutions to the world's toughest transportation problems. The company is headquartered in Chicago, IL and has an employee base of 13,000 people worldwide. Everyone of these workers plays their part in building equipment that moves the rail, mining and marine industries. GE is always trying to help these industries grow by having fuel-efficient and lower emissions freight and passenger locomotives; diesel engines for rail; signaling and software solutions; valued services; drive systems for mining trucks; and marine and stationary power applications.

2.4 Project Description. To research and evaluate the two different options GE has for a solution and then further narrow the solution down to all the specific details. Each team needs to keep in mind the solutions impact to public opinion, on time delivery, freight throughput/capacity, total costs, and emissions/regulatory requirements.

2.5 Project Freight Requirements. There is a current fleet of 50 locomotives, 15 of which will be present in Pittsburgh daily. Three of the fifteen will be mineral trains, the remaining twelve trains will be freight trains. Mineral trains require three locomotives and will carry 12,000 pounds of weight. Freight trains require only two locomotives and will carry 7,000 pounds. All current trains are Tier 2 status.

2.6 Transportation Mode Comparisons.

a. Trucks. All commercial trucks that are found out on major interstates today must follow standards set by the Interstate Highway System. A single axle commercial truck can carry no more than 20,000 pounds, a tandem axle no more than 34,000 pounds and the gross weight of the vehicle can not exceed 80,000 pounds. These values are the absolute maximum weights allowed, however states can set their own regulations on commercial trucks when in state lines. Commercial trucks also release a lot of pollution into the air, and are a fairly slow method of shipping. See Figure 1 for a typical diesel truck and trailer.

b. Barges. Water-way transportation is the kindest mode of transportation to Earth's atmosphere. Of the 3 different shipping methods, barges can by far hold the maximum amount of weight and have the largest load size. The dilemma with this type of shipping is that there is a lot of room for problems. Weather can delay the shipping process, and it's unpredictable in Pittsburgh so there's never a month without any rain. Besides the fact that this method of shipping is slow, it is the most efficient. See Figure 3 for a typical inland waterway barge and tug.

c. Railroad. Locomotives are a very common use for shipping transportation, and have been for a long time. Trains are energy efficient, easily beating out truck transportation. Train freight shipping is very economical compared to other modes of shipping transportation. Shipping by train is inexpensive for companies that have to transport mass quantities fairly regularly. The problem with locomotives is that they are not that flexible and if there is a problem on the track it isn't as easy to fix as one might imagine. During the cold season the tracks become cold which makes for a risky ride some days more than others. See Figure 2 for a typical diesel-electric locomotive.

SECTION 3 TRANSPORTATION INFRASTRUCTURE CONDITION AND CAPACITY

3.1 Introduction. The 2014 Report Card for Pennsylvania Infrastructure evaluates the overall condition of infrastructure in Pennsylvania. The Pennsylvania sector of the American Society of Civil Engineers every few years inspects and grades each section of PA infrastructure which consists of bridges, roads, ports, transit, schools, energy, etc.. This report card is made so that each citizen may know the current condition of the infrastructure they are using. The report card also presents the issues of Pennsylvania's aging infrastructure that must be corrected in order to protect the citizens and the economy of the Commonwealth.

3.2 Pennsylvania Roads and Bridges. For bridges in Pennsylvania, of the 22,660 bridges, 23% of them are considered to be structurally deficient. 19% of Pennsylvania bridges are also considered to be functionally obsolete. Both of the percentiles are significantly higher than the national averages; 23% for structurally deficient bridges being the highest in the nation.. On average more than 16 million vehicles cross the structurally deficient bridges of Pennsylvania each day which makes PA the number four state with the most vehicles crossing structurally deficient bridges in the nation. Historically, PA is known for playing an important role in the nation's infrastructure so bridges subsequently suffer from high truck loads. Harsh, diverse weather conditions also pay huge tolls on Pennsylvania roads and bridges. For roads in Pennsylvania, 23% of roadways are considered as poor which equates up to 9,800 miles of roadway. This does not include the 79,000 miles of roadway owned by local governments and other non-state entities; if assumed to be of equal condition percentage, that means another 18,000 miles of poor condition roads in PA. See Figure 5 for more facts about structurally deficient bridges.

3.3 Pennsylvania Inland Waterways. Overall commercial tonnage most recently calculated is somewhat higher than recent levels while it is still significantly lower than historical levels. Commercial lockages have been measured around 37,000 annual lockages where recreational lockages have been measured around 12,000 annual lockages. Of 17 navigational dams assessed, none of the dams were given a satisfactory rating. Of 17 locks assesses. only 3 of the 17, or 18%, were rated as satisfactory. The condition of the locks is a reflection of their efficiency in processing vessels and tonnage; the condition of the infrastructure is the measurement in terms of the number of annual closures. See Figure 6 for inland waterway funding requirements.

3.4 Pennsylvania Freight Rail System. Pennsylvania has the fifth largest rail system in the United States which has approximately 5,145 route-miles of freight operated railroad and sixty-five freight railroads which is more than any other state. More than half of freight traffic in Pennsylvania, roughly 57%, is through traffic, which means it does not stop or begin within PA's state limits. A large number of rail lines in Pennsylvania are at risk because of an insufficient number of operated trains on those tracks which puts those lines at risk of abandonment. 124 Pennsylvania rail lines are considered to be at risk of abandonment. 96 of those 124 lines are considered especially at risk because annually they carry less than one million gross tons. The Pennsylvania rail network consists of 10% of all freight tonnage in the United States. About 60% of the railroad physical infrastructure is in need of updates, including 170 bridges, each bridge repair roughly costing one million dollars each. Only 70% of the shortline and regional railroads are capable of handling the heavier loads. See Figure 7 for a map of the railroad lines of Pennsylvania.

SECTION 4 STANDARD CAPACITY FOR ALTERNATE TRANSPORTATION MODES

4.1 Cargo Capacity. A 15 barge tow has the largest cargo capacity of 22,500 tons which is equivalent 6,804,000 gallons. In comparison, one barge has approximately 1/15th the capacity holding 1,500 tons or 453,600 gallons. A 100 boxcar railroad train holds 10,500 tons or 3,024,000 gallons which means that one boxcar holds about 105 tons or 30,240 gallons. Similar to the boxcar, a bulk railroad car holds 100 tons or 30,240 gallons. The semi truck has the smallest cargo capacity only being able to hold 26 tons or 7,365 gallons. See Figure 4 for a visual representation.

4.2 Equivalent Units. For a better understanding of the above cargo capacities, the data can be put in terms of equivalents. One barge is equivalent to approximately 15 bulk railroad cars which is equivalent to approximately 58 semi trucks. See Figure 4 for a visual representation.

4.3 Equivalent Lengths. A 15 barge tow is approximately .25 miles long. Using the above equivalent of one 15 barge tow equalling 2.25 100 railroad cars cargo capacity, the length of railroad cars is approximately 2.75 miles long. Comparing this to an equal cargo capacity of trucks (870), the trucks have a length of 11.5 miles. The barge has a significantly lower length than either the railroads cars or trucks. See Figure 4 for a visual representation.

SECTION 5 TRANSPORTATION COSTS AND CONCEPT OF OPERATIONS (ConOps)

5.1 Trucks. Transport by truck is the most expensive of the three transportation methods. Cost per ton mile for truck transport is $5.35 which is much greater than that of barge or rail. The fuel efficiency of truck transport is 155 ton miles per gallon of fuel. Compared to the other modes, truck transport is less fuel efficient too.

5.2 Barges. Transport by barge is the least expensive of the three methods. The cost per ton mile for barge transport is only $.97. The fuel efficiency for barge transport is also the lowest of the three. Barges can get 514 miles for every one ton per gallon of fuel.

5.3 Railroad. Transport by railroad is more expensive than barge transport, but much less expensive than truck. Rail transport costs approximately $2.53 per ton mile. The fuel efficiency of rail transport is also in between barge and truck. Rail transport is able to get 202 miles for every one ton of cargo per gallon of fuel.

5.4 Most Economical Transportation Solution. The transport system that our group chose based on economics alone was a network of all three types of transport. All types of transport must be used since barge and rail transport can only transport cargo to certain areas. The cost to ship cargo using barges was far less than that of railroad cars and trucks, so whenever possible barge transport will be used. The lower cost of shipping is due to the fact that barges are able to haul large quantities of cargo. Barges can only be used for shipping cargo along inland waterways and coastal locations, so rail would be the next transport alternative. Railroad cars can only travel where there are already rails, so trucks would be the last mode of transport to get cargo to their exact destination.

5.5 Concept of Operations (ConOps).

a. General Description. The proposed transport system above will include all three transport modes (barge, rail, truck). Barges will do the majority of the transport by transporting cargo from Pittsburgh to other ports and vice versa. From these ports, the cargo will be transported via rail to all their intended destinations. All locations that cannot be reached via rail will have to be reached by transporting the cargo from rail to trucks and having trucks deliver the cargo. This is the most efficient method since transporting by one mode is either too costly (truck) or not viable (rail/barge).

b. Operational Policies and Constraints. The transport system mentioned above will operate at all hours since this system will be slower than transport by only truck or rail. The staff needed will be about 3-5 people to man each of the barges, 2 people to man the railroad cars, and 1 person for each truck. Additional people will be needed to help transport the cargo from barge to rail and rail to truck and vice versa, and they will be needed to complete any maintenance on the transports. The only space needed should be to store any trucks, trains, or barges that are not in use. This space should be nonexistent since all of these transports should be continually travelling to and from locations. Equipment needed will be 3-4 barges, no trains since there are already trains, and at least 1 or 2 trucks for each location that the cargo is going.

c. Performance characteristics. This system of transport will be slower than simply transporting by rail or truck. Depending on the distance that the cargo has to travel, transport could take 1-2 days or up to a week. Transport should take no longer than a week since all transport will be national. Since barges are the main source of transport in this system, the barges will be able to carry large capacities and drop drop cargo off at ports along the the way. This system minimizes the need for a large amount of trucks. Barges are typically the most reliable transport method while trucks are usually the least reliable. Since the trucks will only have to travel short distance, there should be no issue with reliability. Barges are also the safest transport mode, so limiting the number of trucks will decrease the chance of job related injuries and the amount of security needed.

d. Operational Impacts. The transport system will reduce emissions and help the environment by relying primarily on barge transport. Barge transport has the least amount of diesel emissions and also is the least likely to have a large spill. Communities will appreciate not having to worry about safety and also noise with barges and railroad cars. Minimizing the number of trucks benefits cost as well as the environment.

e. Continuity of Operations. In the event of a catastrophe or natural disaster, barge operation will continue unless there is a blockage in an inland waterway or a hurricane. Railroad operation will continue unless there is a problem with the track or an accident on the tracks. Truck operation may need to be delayed in the case of severe weather and/or an accident. All of these events should only cause delays in the arrival of cargo unless there is an accident involving these transports.

SECTION 6 EPA DIESEL EMISSION STANDARDS

6.1 Background. The first regulation on emission standards for diesel railroad locomotives was adopted during December of 1997 and became effective in the year 2000. The rulemaking applies to all locomotives manufactured or remanufactured from the year 1973. Tier 0-2 standards are met through engine design methods where there is no use of exhaust gas aftertreatment. Another regulation signed March of 2008 imposed more strict regulations. While the 2008 regulations adds more regulations for newly manufactured diesel locomotives, it also includes the more strict regulations for remanufactured Tier 0-2 locomotives. Tier 3 were to be met by engine design methods became effective by 2011-2012. Tier 4 regulations were to be met by required exhaust gas aftertreatment became effective in 2015. To enable the exhaust gas aftertreatments for the Tier 4 standards, EPA allowed the usage low sulfur diesel fuel for locomotives.

6.2 Tier 0-2 Standards.

Line-Haul:

	Year	HC (g/hp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	Smoke (percentage)	Minimum Useful Life (hours/years /miles)
Tier 0:	1973-1992	1.00	9.5 [ABT]	0.22 [ABT]	5.0	30/40/50	(7.5 x hp)/ 10/750,000º
Tier 1:	1993-2004	0.55	7.4 [ABT]	0.22 [ABT]	2.2	25/40/50	(7.5 x hp)/ 10/750,000º (7.5 x hp)/ 10/ -
Tier 2:	2005-2011	0.30	5.5 [ABT]	0.10 [ABT]	1.5	20/40/50	(7.5 x hp) / 10 / -

Switch:

	Year	HC (g/hp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	Smoke (percentage)	Minimum Useful Life (hours/years /miles)
Tier 0:	1973-2001	2.10	11.8 [ABT]	0.26 [ABT]	8.0	30/40/50	(7.5 x hp)/ 10/750,000º
Tier 1:	2002-2004	1.20	11.0 [ABT]	0.26 [ABT]	2.5	25/40/50	(7.5 x hp)/ 10/ -
Tier 2:	2005-2010	0.60	8.1 [ABT]	0.13 [ABT]	2.4	20/40/50	(7.5 x hp)/ 10/ -

6.3 Tier 3-4 Standards.

Line-Haul:

	Year	HC (g/hp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	Smoke (percentage)	Minimum Useful Life (hours/years /miles)
Tier 3:	2012-2014	0.30	5.5 [ABT]	0.10 [ABT]	1.5	20/40/50	(7.5 x hp)/ 10/ -
Tier 4:	2015 +	0.14	1.3 [ABT]	0.03 [ABT]	1.5	_	(7.5 x hp)/ 10/ -

Switch:

	Year	HC (g/hp-hr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	CO (g/bhp-hr)	Smoke (percentage)	Minimum Useful Life (hours/years /miles)
Tier 3:	2011-2014	0.60	5.0 [ABT]	0.10 [ABT]	2.4	20/40/50	(7.5 x hp)/ 10/ -
Tier 4:	2015 +	0.14	1.3 [ABT]	0.03 [ABT]	2.4	_	(7.5 x hp)/ 10/ -

SECTION 7 DIESEL ENGINE EXHAUST EMISSIONS (DEEE)

7.1 Diesel Emission Chemistry. The following data shows the emissions in grams per ton mile of barges, railroad cars, and semi trucks. Barges have the least amount of diesel emissions while trucks have the most diesel emissions.

a. **NOx**. Barge - .46907
Rail - .65423
Truck - .732

b. **Particulate Matter (PM)**.
Barge - .011164
Rail - .01621
Truck - .018

c. **CO_2**.
Barge - 19.3
Rail - 26.9
Truck - 71.6

d. **Hydrocarbons (HC)**.
Barge - .01737
Rail - .02423
Truck - .020

7.2 Diesel Emission Reduction Strategies.

Common diesel reduction technologies include particulate filters, oxidation catalysts, selective catalytic reduction, exhaust gas recirculation, and closed crankcase systems. Particulate filters are filters in diesel engines that are able to remove over 90 percent of particulate matter in diesel exhaust. Oxidation catalysts are used to oxidize hazardous molecules such as carbon monoxide and hydrocarbons into water and carbon dioxide. These catalysts also help to remove particulate matter in emissions. Selective catalytic reduction and exhaust gas recirculation work together to reduce nitrogen oxide emission and improve fuel efficiency. Closed crankcases are another emission technology that reduce emissions from the crankcase of the engine and are now mandated on all newer diesel engines.

7.3 Alternate Fuels.

There are many alternatives to diesel fuel that are cleaner and cheaper. Biodiesel fuel is the most likely fuel to replace diesel. It is a blend of diesel and organically developed biodiesel. Biodiesel is a cheap, cleaner alternative to diesel and can replace diesel in most newer engines without additional modifications to the engine. Another fuel alternative is dimethyl ether. Dimethyl ether has approximately the same fuel efficiency as diesel, but has very low particulate and nitrogen oxide emissions. The drawback to dimethyl ether is that its low density in comparison to diesel means that a much larger fuel tank is needed to store the same amount of fuel as diesel. Other alternatives to diesel include natural gas, electric, and hydrogen. These alternatives have lower emissions than diesel, but natural gas is less efficient while hydrogen and electric can be costly to produce.

7.4 Human Health Issues.

As with any form of freight transportation, pollution is always an issue. Pollution from diesel emissions increases the chances that humans may develop health conditions such as asthma, respiratory disease, and heart/lung disease. Replacing diesel with one of the cleaner alternatives mentioned above would lower the risk of humans developing these health conditions. Another issue with freight transport is the risk of oil spills. The rate of large spills in gallons per ton mile according to the National Waterways Foundation is 2.59 for barges, 4.89 for rail, and 10.41 for trucks. Barges have a much lower danger rate as compared to the other methods based on emissions and spillage.

SECTION 8 LOCOMOTIVE FLEET UPGRADE

8.1 Alternatives. As previously stated, General Electric really only has a few options as to how they can upgrade their fleet. They options are listed out below:

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

8.2 Existing Fleet Make-Up. 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. Upgrading a locomotive fleet is no cheap matter, no matter what decision is made it will be a costly one. To upgrade a Diesel Locomotive from Tier 2 to Tier 3, it will cost about $850,000.00 including the after treatment ($750,000.00 without the after treatment). If a new locomotive is purchased it will cost $3M for Tier 3, and $4M for Tier 4. Alternative fuel options will be $1M for locomotive upgrades, and $1B for a fueling station.

Diesel Locomotive Upgrade

	Tier 2 to Tier 3	After Treatment
Cost	$750,000.00	$100,000.00

New Locomotive

	Tier 3 Locomotive	Tier 4 Locomotive
Cost	$3,000,000.00	$4,000,000.00

Alternative Fuels

	Locomotive Upgrade	Fueling Station
Cost	$1,000,000.00	$1,000,000,000.00

8.4 Upgrade Strategy. The strategy that our design team found most effective would be to buy completely new Tier 3 locomotives for trains past a certain milage, but otherwise just upgrade to Tier 3 if the milage is low. The point at which milage becomes too high is at 450,000 miles. If GE exceeds this milage they will have a hard time selling the locomotive for a good price. At this mileage however, GE can still sell the locomotive for a greater amount of money and put it back into buying brand new locomotives.

8.5 Upgrade Schedule and Costs. The upgrade will include the sale of 20 locomotives and a purchase of 20 brand new locomotives using the money accumulated from the upgrade sales. A yearly calendar for these upgrades cannot be provided at this time as it is unknown when the trains will hit their scheduled mileages. However, since the sales will begin at the start of the new year it is estimated that the upgrade process will be completed at the end of 2016. The estimated sale price per locomotive is $75,000, and the purchase price of new trains will be $3M. This brings the total upgrade cost to $58.5M.

SECTION 9 SUMMARY

In short, the best thing GE can do to keep the people of Pittsburgh happy and meeting the EPA standards is to have a good mix of locomotives and a detailed plan. An alternative to railroad cars would be to transport using barges. Barges have the largest cargo capacity along with having the lowest diesel emissions. The cost to transport with barges is also the lowest, but the disadvantage of barge transport is that barges can only travel along inland waterways and coastal waterways. Trains are the next best alternative to barges having a slightly higher emissions, higher transport cost, and the next largest cargo capacity. Ground transportation is not the company's best option based on the facts that they do not receive good gas milage and the shipping time is slow.

If General Electric decides to change out the fuel their locomotives in effort to decrease the amount of pollution, it would be more than effective, but costs too much. Switching the fuel inside the locomotives will cost the company more than any of the other options. This could be seen as a long term investment if the company does decide to switch, but in reality it's just not worth it.

To conclude our design team would suggest that the company sticks to locomotives. Trains should be sold when they hit 450,000 miles to allow for a good sell price, and also for the safety of the locomotive itself. This will let the company bring in new trains and have money to upgrade the trains that can be salvaged. This strategy will allow the company to earn money back on something that would become useless, to upgrade to the new standards.

SECTION 10 REFERENCES

National Waterways Foundation (nationalwaterwaysfoundation.org)

US Department of Energy (afdc.energy.gov)

Arkansas Waterways Commission (waterways.arkansas.gov)

American Society for Civil Engineers (ASCE), *2010 Report Card for Pennsylvania's Infrastructure:* 2010. Available at http://www.infrastructurereportcard.org.

Figure 1. Typical Diesel Truck and Trailer.

Figure 2. Typical Diesel-Electric locomotive.

Figure 3. Typical Inland Waterways Barge and Tug.

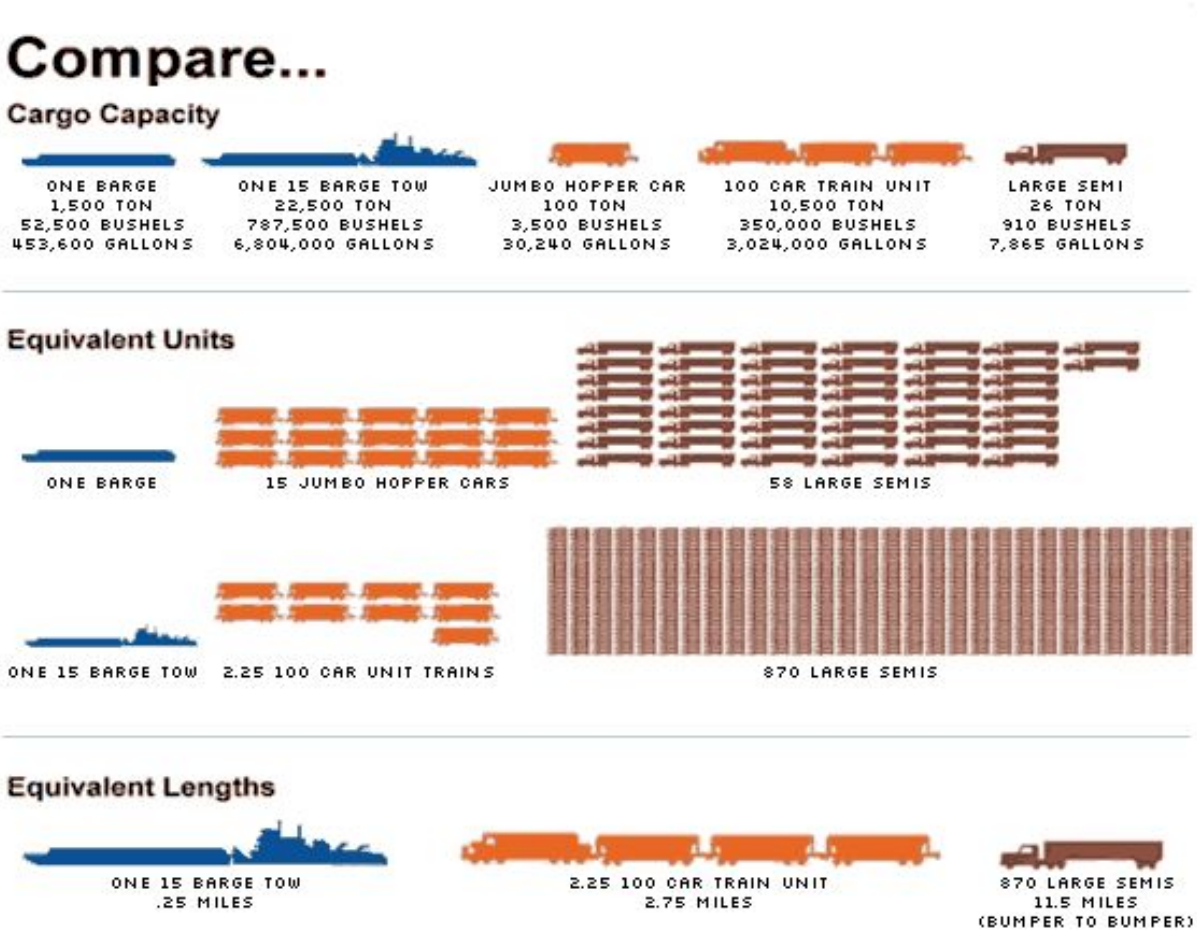

Figure 4. Cargo Capacities of Transport Modes and Equivalencies of Units/Lengths

Figure 5. Facts about Structurally Deficient Bridges in PA.

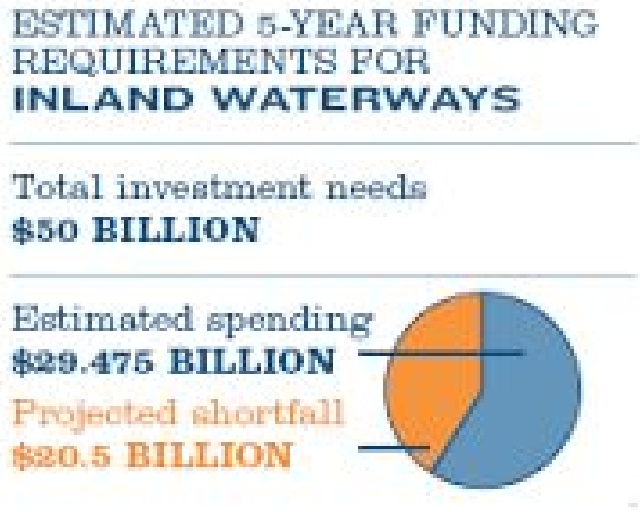

Figure 6. Inland Waterway funding requirements.

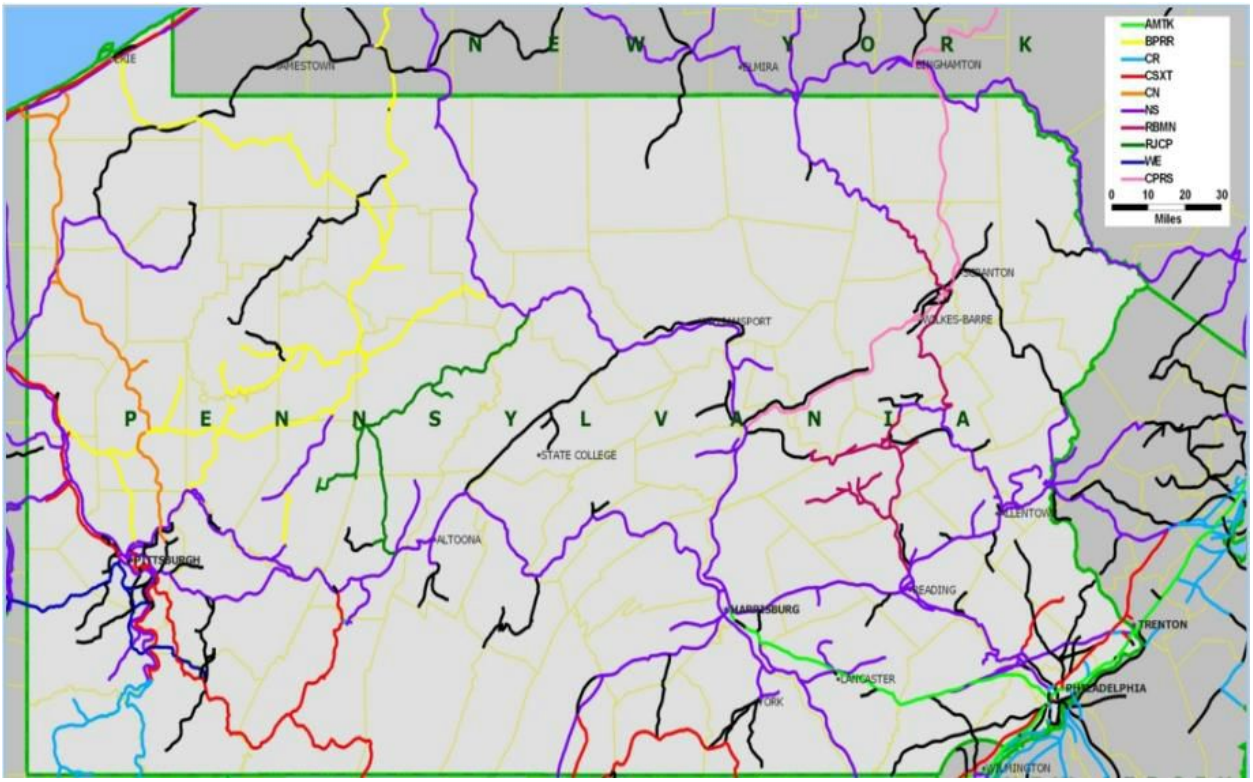

Figure 7. Railroads of Pennsylvania