Executive Summary:
Our solution to GE’s problem was to ship cargo with both freight trains and cargo ships, using the savings from this to upgrade the locomotives to meet EPA requirements. The advantages of this solution are:
- reduced emissions and smog
- reduced fuel cost
- low investment cost
These advantages are significant, over a 2 year period the savings in fuel costs from using cargo ships pays for ¾ of the cost of upgrading the locomotives, with only a slight delay in delivery time.
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**Problem statement:**

Everyday in New York city, approximately 20 Tier-II locomotives filled with freight and coal that enters the city. The smoke emitted by locomotives has affected the city environment and increased air pollution. Also, the smog from locomotives emissions is a key complaint of New York City residents. These Tier-II locomotives are approaching the age of overhaul, which means that it will be required to meet EPA Tier-III requirements to continue operating. Our goal is to look for a cost effective solution which reduces smog, while maintaining or increasing freight capacity. Tier-II locomotives entered the service in 2005. Table 1 is a summary about Tier-II emission and cost:

<table>
<thead>
<tr>
<th></th>
<th>NO\textsubscript{x} emission</th>
<th>PM emission</th>
<th>Fuel cost</th>
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<tbody>
<tr>
<td></td>
<td>375 kg/day</td>
<td>18 kg/day</td>
<td>$34,575/day</td>
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<tr>
<td></td>
<td>136,875 kg/year</td>
<td>6570 kg/year</td>
<td>$126,198,57/year</td>
</tr>
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Table 1: tier-II baseline

**Stakeholders, Customers and Needs:**

The primary stakeholder that the solution was designed for was GE, prioritizing their requirements such as reduction of smog, increased freight capacity, meeting EPA requirements (emission reduction) and cost effectiveness (and related goals such as fuel efficiency and return on investment). The companies and groups indirectly impacted by the solution to GE's problem were identified as; mining companies (coal transport), transportation companies, public (fuel emissions), fossil fuel suppliers, shipping companies, and government. The needs these stakeholders bring to the project include the reduction of noise from locomotives, convenient location of port and short delivery time.

**Concept Generation and Calculations:**

The city selected for the project was New York City, which is conveniently located on the east coast for shipping and for trains carrying cargo along the coast. Three different possible solutions to GE's problem were analyzed to determine the most effective one, and a combination of two of them was found to be most effective.

**Option 1:** Design proposed was to sell all 50 tier II locomotives (which at $1.5 million/locomotive would earn $75 million) and buy 50 new tier III locomotives (which would cost $3 million/locomotive for a total cost of $150 million). This solution carries the benefits of improving fuel efficiency (which saves $64 thousand dollars a day in fuel based on the assumptions of the project). Also the EPA introduced tier IV standards this year, so replacing the fleet would only be a temporary solution until tier IV standards are required.
Option 2: proposed was to upgrade the fleet to tier III standards. This would only cost $37.5 million, more than half of the cost of the investment for replacing the fleet. This would not improve fuel efficiency like replacing the fleet would, but because of the recently introduced tier IV standards a low investment cost is much more preferable.

Option 3: Option 3 consisted of using waterways in tandem with the rail system to drive down transportation costs and increase the amount of cargo that can be transported. The goal was to create a feasible temporary transportation system that would have reduced emissions while operating at a cheaper rate so that the difference between the total amount of money spent on fuel on the new system and the old system over a period of 2 years would be large enough to upgrade the locomotives to tier III at a minimal expense.

Strategy:
A ship was used to transport cargo for a quarter of the total distance. All coal trains were loaded at this intermediate location, whereas the freight trains travelled the entire 500 mile span. However, for every 21st trip they made, the freight trains were also loaded at the intermediate location.

Impact:
The fuel consumption decreased significantly because all the coal trains were now transporting a ton of coal for less than a gallon of diesel and the ship for less than a quarter of a gallon. Furthermore, NO\textsubscript{x} and Carbon Monoxide emissions were reduced by 23% and 16% respectively.

Return On Investment:
Money saved due to diesel cost differences of the original and proposed strategy over a period of two years consists of 26% of the upgradation and after-treatment cost.

Assumptions:
The following assumptions were made for the ideation of this alternative:
- Loading/Unloading time is 30 minutes per train, 1 hour per ship.
- Intermediate cargo port has unlimited storage capacity.
- All transports operate round the clock.
- Empty trains have the same tonnage as Loaded ones.

Calculations:
Cargo tonnage to be transported over two years: 120,450,000

Original Strategy:
Fuel cost of 5 coal trains for 2 years = $232,979,500
Fuel cost of 15 freight trains for 2 years = $407,712,300
Total Cost = $640,691,800
Total NO\textsubscript{x} emissions = 1,830,000
Total CO emissions = 528,000

**Proposed Strategy:**

Fuel cost for 5 coal trains for 2 years = $174,744,480
Fuel cost for 15 freight trains for 2 years = $402,825,110
Fuel cost for ship for 2 years = $53,257,880
Total cost = $630,827,470
Total NO\textsubscript{x} emissions = 1,415,562
Total CO emissions = 444,750

On the basis of this data,

Savings= $9,864,330

**Concept selection:**

**AHP:** The Analytic Hierarchy Process (AHP) helps to rank design features numerically. It works by comparing each criterion with the other and rank them based on their importance, where 5 is the highest, 1 is the lowest. Our team has selected seven criteria for AHP. Our criteria are:

1- Cost: includes both fixed cost and other costs such as maintenance and training.
2- Fuel Efficiency: Meaning that engines produce more efficient power.
3- Emission Reduction: includes the amount of NO\textsubscript{x} and PM emitted.
4- Capacity: meaning that how much goods and freight can be transported.
5- Return on Investment: Meaning the profit from one of the options, as a percent of the amount invested.
6- Noise: Meaning noise produced by one of the options.
7- Delivery Time: Meaning the time it takes to deliver the goods.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>cost</th>
<th>Fuel Ef</th>
<th>Emission Rd</th>
<th>Capacity</th>
<th>ROI</th>
<th>noise</th>
<th>Del time</th>
<th>(\sum_{row})</th>
<th>weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>1</td>
<td>2</td>
<td>0.5</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>15.5</td>
<td>0.21</td>
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<tr>
<td>Fuel Efficiency</td>
<td>0.5</td>
<td>1</td>
<td>0.33</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>20</td>
<td>0.27</td>
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<tr>
<td>Emission reduction</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>12.83</td>
<td>0.17</td>
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<tr>
<td>Capacity</td>
<td>0.33</td>
<td>0.5</td>
<td>0.33</td>
<td>1</td>
<td>0.5</td>
<td>3</td>
<td>0.5</td>
<td>6.1</td>
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<tr>
<td>ROI</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>10</td>
<td>0.13</td>
</tr>
</tbody>
</table>
As can be seen from AHP, fuel efficiency has the highest weight with 0.27, while noise has the lowest weight with 0.04. This implies that fuel efficiency is a determinant factor for all of three options, while noise has a very small effect on our options. These weighted score obtained from the AHP are used to design the Selection Matrix.

**Selection Matrix:** is a quantitative technique that is used to rank and prioritize different options based on the criteria weight obtained from AHP. As we can see, option 3 is the best option with a total weighted score of 4, while option 2 is the worse option with a total weighted score of 2.24.

<table>
<thead>
<tr>
<th>Option</th>
<th>Option 1: Selling locomotives weighted score</th>
<th>Options 2: Upgrade locomotive weighted score</th>
<th>Option 3: Using ship weighted score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Fuel Efficiency</td>
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<td>Emission Reduction</td>
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</tr>
<tr>
<td>Capacity</td>
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<td>1</td>
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</tr>
<tr>
<td>ROI</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Noise</td>
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<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Delivery Time</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>14</td>
<td>24.5</td>
</tr>
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</table>

Table 3: Design selection matrix, Showing option 3 is the best design.
Final Description:
rationale for the recommendation:

Concept of operations:

Our concept starts with the trains and ships being loaded from where the cargo is produced, with cargo that needs to be delivered fast being loaded onto trains and cargo that is not needed immediately being loaded onto ships. They are then fueled for the journey to the port (in New York), where they arrived and are unloaded. After they are unloaded the empty trains and ships are sent back to be reloaded, unless there is something that needs to be sent back, in which case the trains and ships would be sent back full to be reloaded.

System of operation:
Feasibility, adoption, and public opinion: The solution decided upon would be beneficial to some stakeholders and damaging to others. In particular, the solution would benefit mining companies, the public, and shipping companies by reducing coal transport costs, reducing noise and providing a steady stream of business to shipping companies. The solution would damage fossil fuel suppliers because ships require less fuel than locomotives. For this solution to be adopted a partnership or contract between transportation companies and shipping companies would have to formed, and a port where the cargo could be transferred from the trains to the cargo ships would have to be found. Although the overall pollution would be reduced, emissions in New York itself would remain unchanged because there are no changes in the number of locomotives entering and exiting the city. This would, of course, change once the fleet is upgraded to Tier III.

Conclusion:

Our proposed solution seems a practical solution that is able to reduce emission and to minimize cost as much as possible. The proposed solution is accompanied with many advantages to stakeholders, customers, and economy. Our team has agreed that this project taught us a sense of system analyzing through different techniques. We learned how to design an AHP and selection matrix, which is a very effective way to prioritize different option based on
specific criteria. We also learned how translate the idea into a system diagram and concept of operation diagram, which helps the reader to go through the process of how an idea works.

References:
- http://waterways.arkansas.gov/education/Pages/whyWaterways.aspx