The Globo Gym Purple [Co][Br][As]
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Abstract

The citizens of New York have made a request for a design solution that will decrease the amount of smog, specifically NOx and particulate matter, which is emitted from GE locomotives. City officials are open to this idea, but they do not want to decrease the city’s current freight contract with GE. Team 7 has stepped forward to provide a solution which satisfies both of these demands in an economical manner. Team 7 suggests that GE sell all of its current Tier II locomotives and replace them with Tier IV versions retrofitted to accept liquefied natural gas as fuel. Two natural gas facilities will be invested in to supply the locomotives. The extra gas produced by these facilities will be exported overseas to cover the cost. The entire process will pay for itself in 7 years, and there will be numerous benefits for all stakeholders.

Problem Statement

The citizens of New York City would like a shipping system which maintains the current daily delivery capacity of freight and coal while significantly decreasing emissions.

Currently, New York City receives 165,000 tons of freight and coal daily. The coal comes from Pike County, Kentucky and the freight comes from Charleston, South Carolina. These materials are transported on GE locomotives
which meet Tier II government emissions standards. City officials are receiving complaints about the amount of smog these locomotives produce. GE is concerned about potential government penalties which could arise if they do not update their infrastructure to meet the latest emissions standards.

Team 7 will evaluate various alternate methods of shipping along with possible upgrades to GE locomotives in order to create a solution which maintains freight capacity while significantly decreasing emissions of the entire system.

**Background**

Team 7 conducted a considerable amount of research in order to determine the viability of its final design. Initially, Team 7 had to determine the most viable shipping method. Although GE transportation was an important stakeholder for the project, the City of New York was the customer. If satisfying the customer meant abandoning GE’s services in favor of a different type of freight transportation, Team 7 was determined to do just that. However, research showed that locomotives are significantly greener and more efficient than both trucks and airplanes [4]. Shipping via barge was more emission friendly and slightly more energy efficient than locomotive, but it was significantly slower [4]. Team 7 decided that it could best meet project objectives by using only locomotives.
Once Team 7 settled on locomotives, it was important to determine the range of these locomotives. Team 7 discovered that the distance between New York City and Charleston, their freight city, was 640 miles [5], and the distance between New York City and Pike County, their coal city, was approximately 500 miles [5]. After discovering that the fuel tank capacity of GE Tier IV locomotive was only about 5,000 gallons [6], Team 7 could calculate the range of GE’s locomotives, which came to about 700 miles. This knowledge influenced the creation of a significant design component.

Most of the research Team 7 conducted had to do with the export of natural gas. Team 7 determined that natural gas prices in Europe are, on average, four times higher than they are domestically, and as much as six times higher in southeast Asia. However, cost to export to Asia is three times higher than it is to Europe, meaning that the profit made from either market would be essentially the same [1]. Finally, in order to determine the extent of the benefits to all stakeholders, Team 7 researched the number of jobs created by natural gas export operations. Every $1 billion worth of exports creates approximately 6,000 jobs [2].

Finally, in determining the viability of the initial investment, Team 7 researched the annual budget of New York City in order to determine if they were capable of affording such a large initial investment. The tentative budget for 2016 was found to be $77.7 billion [7].
**Customer Needs**

(Table 1: Customer Needs AHP Matrix)

<table>
<thead>
<tr>
<th></th>
<th>Emissions</th>
<th>Regulatory Requirements</th>
<th>Upgrade Cost</th>
<th>Freight Capacity</th>
<th>Public Opinion (Noise Level)</th>
<th>On-Time Delivery</th>
<th>Fuel Efficiency</th>
<th>Aesthetics</th>
<th>Total</th>
<th>Weight</th>
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</thead>
<tbody>
<tr>
<td>Emissions</td>
<td>1</td>
<td>1</td>
<td>1.3</td>
<td>0.5</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>18.80</td>
<td>0.23</td>
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<tr>
<td>Regulatory Requirements</td>
<td>1</td>
<td>1</td>
<td>1.3</td>
<td>1.6</td>
<td>2</td>
<td>4.5</td>
<td>2.5</td>
<td>5</td>
<td>15.00</td>
<td>0.19</td>
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<tr>
<td>Upgrade Cost</td>
<td>0.769230779</td>
<td>0.769230769</td>
<td>1</td>
<td>2</td>
<td>1.5</td>
<td>2</td>
<td>2.2</td>
<td>2.7</td>
<td>12.94</td>
<td>0.16</td>
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<tr>
<td>Freight Capacity</td>
<td>2</td>
<td>0.625</td>
<td>0.5</td>
<td>1</td>
<td>1</td>
<td>1.3</td>
<td>0.7</td>
<td>2</td>
<td>9.13</td>
<td>0.11</td>
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<tr>
<td>Public Opinion (Noise Level)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.666667</td>
<td>1</td>
<td>1</td>
<td>1.7</td>
<td>1.6</td>
<td>1.3</td>
<td>8.27</td>
<td>0.10</td>
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<tr>
<td>On-Time Delivery</td>
<td>0.25</td>
<td>0.4</td>
<td>0.5</td>
<td>0.769231</td>
<td>0.588235</td>
<td>1</td>
<td>0.8</td>
<td>0.9</td>
<td>5.21</td>
<td>0.06</td>
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<tr>
<td>Fuel Efficiency</td>
<td>0.25</td>
<td>0.38461385</td>
<td>0.454545</td>
<td>1.428571</td>
<td>0.625</td>
<td>1.25</td>
<td>1</td>
<td>1.2</td>
<td>6.59</td>
<td>0.08</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0.2</td>
<td>0.333333333</td>
<td>0.37037</td>
<td>0.5</td>
<td>0.769231</td>
<td>1.111111</td>
<td>0.833333333</td>
<td>1</td>
<td>5.12</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Team 7 determined 8 customer needs which it used to evaluate its design concepts. In order of relative weight assigned, they are emissions, regulatory requirements, upgrade cost, freight capacity, public opinion, on-time delivery, fuel efficiency and aesthetics. Emissions are the most important criteria because reducing emissions is the central demand of the customer. Regulatory requirements came second, simply because anything that does not meet regulatory requirements is illegal and not a valid design solution. Upgrade cost comes third; city officials naturally want to use taxpayer money in a responsible manner. A design solution that New York cannot afford, no matter how brilliant, is worthless. Freight
capacity comes fourth because maintaining freight capacity is a central demand of the customer. Public opinion comes next, and it is a very important criterion. This entire project was motivated by public desire to reduce emissions, and the final judgment on Team 7’s success or failure comes from the public. On time delivery is closely tied to maintaining freight capacity, just as fuel efficiency is closely tied to upgrade cost and emissions. Of the eight criteria aesthetics was found to be least important. It plays a role in public opinion, but the public does not have any complaints about the aesthetics of the current system. So long as the aesthetics of the new system are not significantly worse than the old, there should be no significant complaints about aesthetics.

**Concept Generation**

In order to come up with possible design solutions, Team 7 conducted a team brainstorming session. This session resulted in ten different ideas. These ten concepts were narrowed to the four pictured below in Figures 1-4. This parsing was done based on the estimated feasibility of the ten designs. The four pictures below detail the designs which Team 7 deemed had the most realistic chance of making it into the final design.

Figure 1 shows the basic concept behind “Operation Great Lakes.” Team 7 initially intended to obtain New York’s coal from Cheyenne, Wyoming. The idea
behind this concept was to utilize geography and use barges in addition to locomotives to move the coal cross country, eliminating some of the emissions in the process. This idea actually won in Team 7’s concept selection matrix. However, the design team realized that a GE locomotive could not make it back and forth between Cheyenne and New York in one day. Team 7 decided to obtain coal from Pike County, Kentucky instead. Since the Great Lakes do not lie between Kentucky and New York, “Operation Great Lakes” became irrelevant.

Figure 2 shows “Operation Upgrade” which is simply upgrading from Tier II to Tier IV. This concept did become a part of GE’s final design. Team 7 considered only upgrading to Tier III to save money, but since the cost for the extra tier only made up a small portion of the cost of the final design, it was deemed worthwhile to upgrade and meet the latest and greatest government standards, decreasing the smog levels as much as possible in the process.

Figure 3 describes “Operation Fuel Swap” which is simply retrofitting the locomotives to accept liquefied natural gas. It is an 80% replacement, meaning that the locomotives still need to get 20% of their fuel from diesel. The benefits of this change are considerable, most significantly the 50% decrease in fuel costs. This concept became an integral part of Team 7’s final design.

Figure 4 shows “Operation All of the Above” which was simply the idea to use whatever combination of airplanes, trucks, barges, and locomotives worked
best environmentally while remaining economically feasible. This was a very vague concept, essentially meaning that Team 7 left themselves open to all options. This concept was abandoned in favor of a system that only utilized locomotives for moving freight.

(Figure 1: Operation Great Lakes)  
(Figure 2: Operation Upgrade)  
(Figure 3: Operation Fuel Swap)  
(Figure 4: Operation All of the Above)
After the discussion within the team, Team 7 did an online anonymous voting in which the great lakes idea ranked the highest and the combination idea ranked the second which narrowed down our choices. Furthermore, Team 7 worked on the concept selection matrix which is show above. In the concept selection matrix, Team 7 compared the great lakes idea and the combination idea. In this matrix, the great lakes idea won, but as we were developing the system, Team 7 figured the distance shipping by boats is too far and therefore it would take too long, so based on the original great lakes idea, we ended up coming up with a system that was better than both of these original ideas. This idea was the natural gas design.
Concept Development, Cost-Benefit Analysis, and Selection

(Table 3: Fixed Costs vs. Variable Costs)

<table>
<thead>
<tr>
<th>Fixed Costs</th>
<th>Variable Costs:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$4M Per Tier IV locomotive</td>
<td>International Price of Liquefied Natural Gas</td>
</tr>
<tr>
<td>$1M per natural gas retrofit kit per locomotive</td>
<td>Diesel Prices</td>
</tr>
<tr>
<td>$1.5M sale price for old Tier II locomotive</td>
<td>City of New York Budget</td>
</tr>
<tr>
<td>$2B for two new Liquefied Natural Gas Fuel Stations</td>
<td></td>
</tr>
</tbody>
</table>

(Table 4: The Cost and Benefits table)

<table>
<thead>
<tr>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very large investment</td>
<td>Significant decrease in smog and emissions</td>
</tr>
<tr>
<td>Potential ethical conflict</td>
<td>50% cut in GE's daily fuel costs after 6</td>
</tr>
<tr>
<td></td>
<td>Years</td>
</tr>
<tr>
<td>----------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Brings jobs and a new industry to the Cities of New York and Charleston</td>
</tr>
<tr>
<td></td>
<td>Creates a new source of income for both cities after 6 years, expansion on the city's current freight contract with GE, or some combination of the two</td>
</tr>
</tbody>
</table>

Team 7 has abandoned Design 1 for geographical reasons. Team 7 originally planned to obtain New York’s coal from Cheyenne, Wyoming, the capital of America’s leading state in coal mining. However, it was over 1650 miles from Cheyenne to New York. Moving at a mere 50 miles per hour, the locomotives could not travel back and forth within 24 hours. Team 7 has decided to obtain coal from Pike County, Kentucky. Kentucky is the third leading state in terms of coal production, and Pike County, Kentucky’s second largest mining district, is just over 500 miles from New York City. When traveling from Cheyenne, Team 7 considered using the Great Lakes as part of the journey. Because there are no large bodies of water between Pike County and New York City, Design 1 is no longer a feasible option. However, Team 7 finished the comparison for the purpose of the assignment.
Team 7 will propose that the City of New York fund the installation of a Liquefied Natural Gas facility. This will provide jobs for local professionals and give business to local construction contractors. The City of New York will also invest $250M to upgrade GE’s fleet of 50 locomotive to the new Tier IV model. The city will receive the revenue from the sale of the outdated Tier II models for a net expenditure of $1.175B. GE currently spends just over $500,000 daily to fuel their locomotive powered trains which travel between New York, NY; Charleston, SC; and Pike County, KE daily. The natural gas retrofit kit will cut GE’s fuel costs in half per the data from the GE project. GE will continue to spend $500,000 daily on fuel, giving the right to $250,000 worth of natural gas to the City of New York daily. As a port city, New York is ideally placed to export this gas to Europe, where natural gas prices are significantly higher than they are domestically. Per Team 7’s calculations, which can be produced upon request, after accounting for the cost of transport, the City of New York will be able to reap a threefold profit on its exports for an income of $750,000 daily and $274M annually. At this rate the investment will take 4.3 years to repay itself, more than twice the target number. However, the extra time will be well worth it for all stakeholders. Once the new infrastructure is paid off, GE will have its daily fuel costs slashed in half. The City of New York will have the option to continue exporting natural gas, for a profit of $500,000 daily and $182.5M annually, or they can expand their contract with GE.
Per the guidelines of the GE project, a $1B LNG plant has the capacity to deliver enough natural gas to fuel GE’s current efforts along with a 25% expansion. The City of New York would be free to continue to export this extra natural gas or allow GE to buy it and expand their contracts with the city.

**Design Review**

The teams that critiqued Team 7’s design did not have a whole lot to add. While understanding that Team 7 was still fairly early in the design process, they encouraged the team to get all of the numbers and evidence required to support the proposal. Team 7 definitely took this advice very seriously. By the end of the design process, Team 7’s attention to detail with regard to numbers was praised as one of the best aspects of the design.
Description of Final Design

(Figure 5: The Final Design Model)

Team 7’s design requires an up-front investment of $2.18 billion. This will cover the purchase of 51 new Tier IV locomotives, the natural gas retrofit upgrades to these locomotives, and the purchase of two natural gas plants to supply fuel for the locomotives. This investment covers all aspects of the project objective. The new locomotives will cut particulate matter emissions by 85% and NOx emissions by 76%. The natural gas plants will provide enough fuel for the locomotives with a significant amount left over. Finally, the 51st locomotive will transport natural gas between Charleston and Pike County, ensuring that the coal trains have enough fuel to make the return trip to New York. The return on investment, 7 years, is
longer than the ideal value given by GE, two years, but Team 7 feels that the many benefits to all stakeholders, summarized below, make it worth the extra time.

GE will immediately receive all new locomotives which meet the latest government standards. Also, after a period of 7 years, they will have their daily fuel expenditures cut from $500,000 to $250,000, saving them $91.25 million per year. New York City, the customer for this project, will experience 85% less particulate matter emissions and 76% less NOx emissions from GE locomotives. This means a significant decrease in smog, which meets the demands of the citizens. The building of the natural gas plant will give work to local construction contractors, and the new export industry will create jobs for citizens. Finally, after a period of 7 years, the city will begin making money on its investment, approximately $110 million annually. This extra income can be used to expand their current freight contract with GE or in any other manner that city officials see fit. The City of Charleston will receive all the same benefits as New York, including cleaner air, new jobs from their natural gas plant, and an annual income of approximately $110 million after the period of 7 years, with the added caveat that they will not be asked to make a contribution to the initial investment.
This system diagram illustrates qualitatively how inputs and outputs make their way into and out of the system respectively. For example, natural gas and diesel are always inputs for the locomotives and emissions are always an output;
these are both natural consequences of operating locomotives. Also, the materials being moved, whether freight and coal to New York or natural gas for export, are always shown as inputs or outputs at the appropriate stage of the system.

Concept of Operations

(Figure 7: CONOPS)

This CONOPS system diagram provides a quantitative illustration of how materials and money move through the system on a daily basis. For example, it shows that 294,000 gallons of natural gas and 4,090 gallons of diesel are required
to power the 30 locomotives which transport 105,000 tons freight between Charleston and New York every day.

**Conclusion**

The system design is essentially to upgrade GE’s current fleet of locomotives, build fueling stations to power them, and sell off the extra fuel to pay for the entire operation. The benefits are new infrastructure and reduced fuel costs for GE and less smog and considerable economic stimulus for New York City and Charleston. The main cons are the long return on investment, the displacement of GE’s current fuel suppliers, and dependence on foreign natural gas prices, which is a variable factor. This design could be significantly improved by taking into account government benefits for projects which reduce emissions. This could potentially decrease the return on investment by a significant amount and decrease the project’s reliability on foreign natural gas prices.

One of the main lessons Team 7 learned from this project was the value of being thorough. Team 7 was able to answer all challenges to their design by having a firm grasp of the specific data backing up their assertions. Also, the team learned a great deal about the effect that politics and foreign events can have domestically. For example, one of the reasons natural gas prices are so high in Europe is because they have limited natural gas reserves and are hesitant to resort to fracking to
extract what they do have. This has made them extremely reliant on Russia for natural gas imports, and Putin has not been shy to take advantage of what is essentially a monopoly [8]. This gives them a significant incentive to import gas from elsewhere. It is important as an engineer to have both sound data and an understanding of the way that data fits into the surrounding world. Brilliant solutions necessitate this type of precision and awareness.
Work Cited:


“Distance from Charleston- Pike County”. 32°46’57.6”N, 79°53’07.92”W - 37°27’41.82”N,82°24’08.82”W. Google Earth. April 9, 2013. December 13. 2015
“Distance from Pike County- New York”. 37°27’41.82”N, 82°24’08.82”W- 40°39’13.67”N, 74°01’27.02”W. Google Earth. April 9, 2013. December 13, 2015.

