GE Retrofit Kit: Converting to Diesel-LNG Fueling
Client: General Electric

EDSGN 100; Section 25
Instructor: Dr. Sarah Ritter
December 14, 2015

Team 2: Legally Blind
Rachael Beaver, John Kelley, Prajesh Patel, Nurfarahim Jesni
rjb5808@psu.edu, jbk5383@psu.edu, pbp5086@psu.edu, nbj5051@psu.edu
Abstract:
The smog produced by locomotives poses an environmental threat to the regions near St. Louis. The diesel consumption process in locomotives has been identified to generate large amounts of particulate matter, NOx, carbon monoxide, and hydrocarbons as harmful byproducts. Changing the fuel consumed by locomotives would require changing most of the existing infrastructure, which would not be feasible. Therefore, upgrading the system to consume LNG and diesel was the ideal choice. The improved system was cost effective and reduced the emissions drastically while improving fuel efficiency and maintaining freight capacity.

Introduction and Problem Statement:
In the community we chose for this project, St. Louis, smog emitted from transportation is destroying the environment and, according to health reports, negatively impacting the health of its citizens. If this problem is not solved in coming years, these harmful effects from transportation emissions will continue. Because of the destruction from smog, the community of St.Louis would like to reduce transportation emissions while maintaining delivery time and freight capacity. We plan to research all possible forms of transportation, the benefits of each, and different ways each mode could be improved. From here, we will look into combining different solutions, and come up with the most feasible idea to help the citizens of St. Louis.

Background:
Currently, there are 50 Tier II locomotives traveling 500 mi to and from St. Louis daily. Because these locomotives are Tier II, each locomotive emits about 22,275 kg of NOx and 810 kg of PM per day. On top of this, the cost for fuel is approximately $286,704,215 per year. In an effort to reduce emissions from locomotives in the future, the EPA has been setting emission standards. Currently, there are four tiers— with each increasing tier, the level of emissions decreases. For Tier IV, the highest standard, the level of PM is .03 and level of NOx is 1.3, a dramatic decrease compared to the level for Tier II locomotives, which is .13 PM and 8.1 NOx. The ultimate goal is for future methods of transportation to meet Tier IV standards.
Customer Needs:

The customers ultimately wanted for our solution to reduce smog, maintain the power of transportation, the price to stay relatively the same, the time of delivery to be maintained, the EPA Tier IV standards to be met, the freight capacity to be maintained, and the fuel efficiency to increase. Because of these needs, we chose these categories, along with public opinion, to rate our design. Table 1 shows the AHP Matrix we used to rate these needs against each other to see which were most important. We translated our results into the bar graph, Figure 1, showing the customer needs compared to the weight values from our AHP matrix. Smog reduction, freight capacity, fuel efficiency, and emission standards were our highest rated categories. This is because our main goal was to reduce smog and emissions while maintaining freight capacity. Our lowest ranked category was public opinion. While we thought public opinion was very important, we felt that by placing importance on the other categories, the public would be most content with our solution, which is why it’s rated lowest.

Table 1: AHP Matrix of Customer Needs

<table>
<thead>
<tr>
<th></th>
<th>Reduce Smog</th>
<th>Power</th>
<th>Cost</th>
<th>Time Efficiency</th>
<th>Emmission standards</th>
<th>Public Opinion</th>
<th>Freight Capacity</th>
<th>Fuel Efficiency</th>
<th>Total</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Smog</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>20.00</td>
<td>0.21</td>
</tr>
<tr>
<td>Power</td>
<td>0.333333333</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>0.33</td>
<td>1</td>
<td>0.6</td>
<td>0.5</td>
<td>9.76</td>
<td>0.10</td>
</tr>
<tr>
<td>Cost</td>
<td>0.2</td>
<td>0.3333333</td>
<td>1</td>
<td>3</td>
<td>0.33</td>
<td>2</td>
<td>0.2</td>
<td>0.25</td>
<td>7.31</td>
<td>0.08</td>
</tr>
<tr>
<td>Time Efficiency</td>
<td>0.2</td>
<td>0.3333333</td>
<td>0.3333333</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>0.2</td>
<td>5.57</td>
<td>0.06</td>
</tr>
<tr>
<td>Emmission standards</td>
<td>1</td>
<td>3.030303</td>
<td>3.030303</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>15.06</td>
<td>0.16</td>
</tr>
<tr>
<td>Public Opinion</td>
<td>0.333333333</td>
<td>1</td>
<td>0.5</td>
<td>1</td>
<td>0.333333333</td>
<td>1</td>
<td>0.25</td>
<td>0.5</td>
<td>4.92</td>
<td>0.05</td>
</tr>
<tr>
<td>Freight Capacity</td>
<td>1</td>
<td>1.6666666</td>
<td>5</td>
<td>0.5</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>18.17</td>
<td>0.19</td>
</tr>
<tr>
<td>Fuel Efficiency</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>0.25</td>
<td>1</td>
<td>16.25</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Grand Total: 97.04
Concept Generation:

For our concept generation, we started by individually brainstorming ideas, each producing over seven. Some of our best ideas included: a hydraulic engine on our locomotives, installing solar panels onto the trains, a hyperloop, changing the fuel source, upgrading tiers, and using a combination of locomotives and trucks, among others. We then used the TASC selection method, which ranked our ideas based on words we chose to describe each idea. This narrowed our ideas to our top three, which were: implementing solar panels onto the train, upgrading our locomotives to Tier IV, and finally changing the fuel source. Once we got to this point, our team became divided about making the final choice. Due to this, we decided to rank the top three ideas in another selection matrix.

<table>
<thead>
<tr>
<th>(weights)</th>
<th>Cost (2)</th>
<th>Freight Capacity (3)</th>
<th>Emissions (4)</th>
<th>Fuel Efficiency (1)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Panels</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>Change to Tier IV</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>39</td>
</tr>
<tr>
<td>Upgrade Fuel</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>34</td>
</tr>
</tbody>
</table>

According to our selection matrix, solar panels would have been our best solution. However, after doing some calculations we deemed solar panels inadequate, because the trains did not provide the surface area necessary for the required energy. We realized that
both the infrastructure necessary for solar panels and the cost to purchase/install them was infeasible.

Because our idea for the solar panels didn’t pan out, we ran numbers for our second and third ideas—upgrading our trains to Tier IV and changing the fuel source. Out of those two ideas, we decided that our third idea, changing the fuel source, was our most feasible idea, and chose it for our project. In the next section, we will explain in more depth why we decided to go with LNG fueling over upgrading tiers or solar panels.

**Concept Development, Cost-Benefit Analysis, Selection:**

Our initial step was to illustrate multiple ideas and compare the most impactful designs. We chose the top eight out of the initial thirty-two ideas. Narrowing down allowed us not only to choose from logical ideas, but the feasible ones as well. We used the TASC idea selection method to select our top three choices. Although the TASC selection method ranked our solar panel idea as the highest, we moved on with changing the fuel after further analysis.

**SOLAR PANELS**

Implementing solar panels onto the locomotive would eliminate all emissions because it’s a renewable energy source. While this method is clean and environmentally friendly, it has several downsides to it: Implementing this solution requires a large investment, as solar panels are very expensive. They are also not efficient and therefore require many panels to generate the required 4500 horsepower to run the train. Unfortunately, the locomotive does not have enough surface area to fit the required number of panels. This would generate less power than the existing model and therefore not be feasible (Railway Technical Web Pages).

**UPGRADE TO TIER IV**

Upgrading all fifty Tier II locomotives to Tier IV will reduce smog and emissions by a considerable amount compared to just changing the fuel and would meet our standards for emission reductions as well as smog reduction, power, delivery time, freight capacity, fuel efficiency, and public opinion (Schilling). In terms of cost however, we figured it would take approximately 11 years to earn back the money spent to upgrade all 50 locomotives. If we wanted a two year return of investment, we would only be able to upgrade 18. For a 5 year ROI, we could upgrade about 20. Clearly, for a lower return of investment period, we would have to sacrifice the amount of emissions we could reduce. This simply didn’t seem feasible.
CHANGING FUEL

We moved on to our third design, changing the fuel to Diesel–LNG through GE’s Retrofit Kits. Because the Tier II locomotives we owned were older than ten years, it would only cost $500,000 for each retrofit kit (GE). The cost of fuel and setting up a fuel station had to be considered to implement this idea. The fuel cost for using diesel–LNG as fuel for one year is $100,621,375. However, setting up a LNG fuel station costs approximately $1 billion. This is the cost to set up the fueling station and is only required for the first year. Every year after the first would require approximately $1 million, which pays off the maintenance and the fuel cost. The return of investment would therefore take six years, the only downside of this solution.

Changing the fuel from only diesel to Diesel–LNG allowed us to reduce the emissions and smog. With this solution, we reduced the NOx emissions by 76% while reducing particulate matter by 70%. Along with reducing smog, we were able to maintain the transport capacity of coal and freight locomotives.

This design proved to be much better than our first two ideas. Not only did it meet every customer need except cost, but it exceeded our expectations in fuel efficiency (the fuel change would increase the mpg and decrease the cost of fuel by 50%) and even met Tier IV emission standards (Braymer). We knew our idea for solar panels was infeasible, but after comparing upgrading our locomotives to Tier IV and changing the fuel source, it was clear that changing the fuel source was our best idea, though ranked lowest on our selection matrix. Upgrading all locomotives to Tier IV, would have been much more expensive for minimally better results, or for a lower price, we would have sacrificed the amount of emissions reduced.

Table 3: The cost per year to implement the changing the fuel idea.

<table>
<thead>
<tr>
<th>Tier II Spending per year</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Train</td>
<td>$286,704,215</td>
<td>$286,704,215</td>
<td>$286,704,215</td>
</tr>
<tr>
<td>Diesel–LNG Train</td>
<td>$1,225,621,375</td>
<td>$100,621,375</td>
<td>$100,621,375</td>
</tr>
</tbody>
</table>
Design Review:

The design review did not really affect our final design. The reason for this is that we had not finished running numbers for our second and third ideas, and therefore did not have a final plan at that point in the process. During the design review, we described our options of upgrading to Tier IV, changing the fuel, or a combination of both to the other groups, but because we did not have the cost analysis finished for these ideas, the other groups did not have much input about which was best. Ultimately, we decided on changing the fuel source, as it became clear that it was the most feasible idea (Smith).
Final Design:

For our final design, we decided to upgrade all 50 of our Tier II locomotives to using a combination of 20% Diesel and 80% LNG fuel. To do this, we will simply purchase 50 of GE’s Retrofit Kits, which cost $500,000 per train, since they are older than 10 years. In terms of infrastructure to support this design, we will also need to purchase an LNG fueling station for $1 billion for the 500 mile trip to and from St. Louis (Williams).

<table>
<thead>
<tr>
<th>Tier II Emission</th>
<th>NOx Emission</th>
<th>PM Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Train</td>
<td>5.5 gm/hp-hr</td>
<td>22,275 kg</td>
</tr>
<tr>
<td>Diesel-LNG Train</td>
<td>1.32 gm/hp-hr</td>
<td>2,320 kg/day</td>
</tr>
</tbody>
</table>

This solution meets all but one of our standards. In terms of emissions, this solution will reduce current PM emissions by 70% and NOx emissions by 76%, which not only meets our customer needs for emissions and smog reduction, but even greater, meets the EPA Tier IV emission standards as well. Overall, this will greatly help the environment by reducing the amount of smog and pollution in the air. On top of this huge reduction in emissions, the trains’ freight capacity, power, and speed of delivery were maintained, and fuel efficiency was actually increased, meeting our customer needs.

The only area where this solution did not meet our standards was cost. Because of the combined cost of purchasing 50 retrofit kits and a fueling station, the return of investment would be six years. Obviously, this does not meet our ideal time frame of just two years, but is definitely not an outrageous amount of time. Even though this investment may not meet our standards, we do think it will save the company much money over time. Because of the higher mpg of LNG fuel, using the kits to upgrade the fueling will save 50% in fuel costs in the long run.

Overall, we feel that the public opinion will be very positive towards this solution, since it meets every standard except for cost, which really won’t affect the public. The only concerns we think the public may have is in using LNG fuel, since it’s a nonrenewable resource, but we think the pros will outweigh this concern.
The Systems Diagram in Figure 3 shows how the train will work using Diesel and LNG fuel. The first three steps show that the Diesel fuel is only used to start the train. After ignition, LNG fuel is used to move the train, which is why only 20% Diesel fuel is required.

The inputs of our system as a whole will be 50 Retrofit Kits to upgrade the trains and a LNG fuel station for the 50 locomotives that currently travel 500 miles to and from St. Louis daily. This will output of 70–76% emission reductions, higher fuel efficiency, and maintained delivery time and freight capacity. This solution will greatly improve the city, as it will decrease pollution and meet the needs of its citizens. It will also please the suppliers, as delivery time and freight capacity were maintained and fuel efficiency was increased.

Concept of Operations:
Conclusions:

Overall, there are many pros to our solution. First of all, our solution maintains freight capacity, power, and delivery time, which were all important standards for both our customers and the public. Even better, the design reduces PM emissions by 70% and NOx emissions by 76%. This is a huge reduction in emissions, and meets EPA Tier IV standards. This was the main goal of our project, making this reduction a major pro of our design. We feel that the public opinion will be extremely positive toward all of these aspects.

The only con of this design is the return of investment, which will be six years. Ideally, we hoped for two years, but we don’t think six years is a drastic increase. The longer time frame is balanced by the fact that the company will save 50% in fuel costs every year by upgrading to Diesel-LNG fuel.

In conclusion, we think upgrading our fuel to Diesel-LNG through GE’s Retrofit Kits is a very feasible option, with the only drawback being the length of the return of investment period.
References


