Team 3 - Overbuilt and Underpaid
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Abstract

GE wants to reduce the smog in the city of Boston. Due to the 165,000 tons of freight that goes in and out of city every day, the Tier II locomotives release mass amounts of NOx into the atmosphere. This causes smog which is an environmental issue as well as a widespread complaint of the city residents. Because of this, GE wants to invest money into bettering the NOx, PM, and CO emissions while having a return on investment (ROI) of 2 years. There are many ways to solve this problem, but we chose to embrace simplicity in the design of our solution. Our team decided on a 3-prong approach: to upgrade each Tier II locomotive to Tier III, give each locomotive an aftertreatment (open system catalytic reduction), and use biodiesel 20 (B20) as alternative fuel. Using this method, we reduced NOx by 70-90%, PM by 66%, and CO by 15% while having a return on investment of 2 years.

Project Statement

Boston would like to improve upon the current freight system in place by bettering the environmental effects while maintaining the efficiency and effectiveness of the current system. Today, Boston uses locomotives that fall under Tier II Environmental Protection Agency (EPA) standards. These low, out of date standards could prove dangerous for future generations. Therefore, our group wishes to improve on the NOx and PM emissions by reaching at least Tier III EPA standards. By analyzing economic and environmental effects in similar locomotive and freight systems, the optimal transportation infrastructure for GE can be achieved.

Background

The three main changes that our group is utilizing are upgrading all Tier II locomotives to Tier III, applying the open system catalytic reduction aftertreatment, and utilizing B20 to replace diesel. Currently, GE utilizes only Tier II locomotives thus are seeking an improvement in Tier III to combat emissions. Biodiesel 20 is a clean-burning and renewable substitute for petroleum diesel that consists of 20% biodiesel and 80% petroleum diesel. To combat PM emissions, both the change to Tier III and change to B20 will reduce PM. B20 accounts for 12% of the reduction
in PM [4]. Open system catalytic reduction aftertreatment's main purpose is to counteract the NOx emissions. With a 70-90% reduction rate in NOx, open system catalytic reduction converts NOx emissions into nitrogen, water, minute amounts of carbon dioxide, and natural components of the air that we breathe [1].

**Customer Need**

We collectively decided that time efficiency, environmental friendliness, effectiveness, loudness, resource efficiency, unobtrusiveness, cost effectiveness, and durability would be our customers’ needs as shown in [Table 1] below. We compared the customer needs using an AHP matrix [Table 2]. Our findings were that environmentally friendly was our number one priority, followed by resource efficiency and effectiveness. The matrix was converted into a pie chart [Figure 1] to help visualize the rankings.

By upgrading to Tier III locomotives, we ensure effectiveness because the horsepower of the trains does not deplete when the locomotive is upgraded. Tier III locomotives are also more environmentally friendly than Tier II locomotives and prove to have less harmful emissions. Upgrading to Tier III locomotives will not interrupt people’s daily lives because we will be using the same infrastructures that were in place before. Hence, our process is unobtrusive or at least not anymore obtrusive than it was before. Tier III locomotives will provide about the same durability, time efficiency, and loudness as the locomotives in the past. While upgrading to Tier III will not technically improve durability, time efficiency, unobtrusiveness, and loudness, it will not deplete those needs either. Tier III locomotives will be more resource efficient because they release less pollution while using the same fuel. By upgrading to Tier III locomotives, we will be able to save on pollution clean up, thus making our process cost effective. Upgrading to Tier III locomotives meets all of our customer needs.
<table>
<thead>
<tr>
<th>Customer Needs</th>
<th>Acceptable Specifications</th>
<th>Ideal Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Efficient</td>
<td>No added delivery time</td>
<td>Decreased delivery time</td>
</tr>
<tr>
<td>Environmentally Friendly</td>
<td>Meet Tier III EPA requirement</td>
<td>Meet Tier IV EPA requirement</td>
</tr>
<tr>
<td>Effective</td>
<td>Maintains 165,000 tons of freight daily</td>
<td>Transports 200,000 tons of freight daily</td>
</tr>
<tr>
<td>Loudness</td>
<td>95% of people are satisfied with noise level</td>
<td>All people are satisfied with noise level</td>
</tr>
<tr>
<td>Resource Efficient</td>
<td>Uses the same amount of fuel</td>
<td>Uses 80% of fuel</td>
</tr>
<tr>
<td>Unobtrusive (to their daily life)</td>
<td>Expands 10% on current used land</td>
<td>Does not expand on current used land</td>
</tr>
<tr>
<td>Cost Effective</td>
<td>ROI 2 years</td>
<td>ROI 1 years</td>
</tr>
<tr>
<td>Durability</td>
<td>Can be maintained until needed to be replaced for next upgrade</td>
<td>Can be maintained until next upgrade</td>
</tr>
</tbody>
</table>

*Table 1.* Customer needs along with the acceptable and ideal specifications.
Figure 1. This is a pie chart of the AHP matrix.

Table 2. AHP Matrix of our customer needs including weights.
Concept Generation

During concept generation, we individually brainstormed as many ideas as possible. We then collectively decided on which ideas should progress to the next phase of generation. We ruled out impossible and highly improbable ideas. A program called Tool for Assessing Semantic Creativity (TASC) was used to help order our ideas from least to most creative. TASC is a program that shows a user an idea and the user selects words from a predetermined list that they feel apply to the idea. Each word is weighted by the program based on how creative the word is. The ideas that were left after our original brainstorming session were entered into TASC. As individuals, we rated each idea in TASC and it ranked them for us in order of creativity. Our original ideas after ruling out the were a locomotive powered by solar panels [Figure 2]. The next idea was upgrading the locomotives to use pure biodiesel and take boat part way [Figure 3]. Our next idea was taking a plane part way then off loading to a boat to a train station that utilized Tier III locomotives to finish the delivery [Figure 4]. The last idea that made it into TASC was taking a boat part way and Tier III locomotives the rest of the way to the destination [Figure 5].

Figure 2. Idea #1 included solar panel tracks and a hybrid train.
**Figure 3.** This is idea #2 from the TACS idea generation

**Figure 4.** This is idea #3 from the TACS idea generation

**Figure 5.** This is idea #4 from the TACS idea generation
Concept Selection

We reviewed the results from the TASC engineering design selection [5] and had decided that the winning ideas were not the best ideas. After all, concept selection does not decide for you; TACS only guides your decision. The idea we ultimately chose was not actually one of the original ideas. Many of our original ideas were very far-fetched and seemed too complicated to be practical in the real world. With this in mind, we pushed forward with our idea to upgrade the locomotives to Tier III, use B20 fuel, and include a open system catalytic reduction aftertreatment. We came to a conclusion that using other modes of transportation could lead to unexpected complications and therefore would only complicate our concept. Ultimately, we decided that simplicity is the best way and that our concept was simple, effective, and met our customer needs. After evaluating our concept against the ideas we had for the TASC engineering design selection [5] in our scoring matrix [Table 3], we found that our concept of Tier III locomotives with B20 fuel and an open system catalytic reduction aftertreatment was the highest scoring idea. Thus, we pursued our simple yet effective design.

<table>
<thead>
<tr>
<th>Customer Need</th>
<th>Time Efficient</th>
<th>Environmentally Friendly</th>
<th>Effective</th>
<th>Loudness</th>
<th>Resource Efficient</th>
<th>Unobtrusive</th>
<th>Cost Efficient</th>
<th>Durability</th>
<th>Total (weighted)</th>
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<tbody>
<tr>
<td>Proposed Solutions:</td>
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<td></td>
<td></td>
<td></td>
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<td>Aerodynamic Locomotives</td>
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<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>91</td>
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<td>Solar Powered Train Tracks with Hybrid Locomotives</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>103</td>
</tr>
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<td>Use Airplane, Boat, and Tier III Locomotive</td>
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<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>79</td>
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<td>Biodiesel Locomotive to NYC to Boston</td>
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<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<td>96</td>
</tr>
<tr>
<td>Use Boat and Tier III Locomotive</td>
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<td>3</td>
<td>3</td>
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<td>3</td>
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<td>Tier III Locomotives with B20 and after treatment</td>
<td>3</td>
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<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>125</td>
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</tbody>
</table>

Table 3. This is the table used to select our best idea according to the weights given to each customer need.
Cost Benefit Analysis

What we know:

- 20 trains per day
  - 15 freight w/ 2 locomotives (7,000 tons each)
  - 5 coal w/ 3 locomotives (12,000 tons each)
- Total number of locomotives active each day: 45
- Fleet size: 50
- “Mileage” for a Tier III B20 locomotive
  - 1 ton of freight 470 miles on 1 gallon of diesel
  - locomotive horsepower= 4500 hp
- capacity per day= 165,000 tons
- emissions Tier III
  - PM= .1 g/hp-hr
  - NOx= 5.5 g/hp-hr

Assumptions:

- 550 miles from Richmond to Boston
- 300 miles from Scranton to Boston
- average speed of train= 50 mph
- coal trains weigh 1000 tons
- freight trains leave with 500 tons of freight/ train
- B20= $2.93/ gallon [4]

Case Study 1 (amount spent on B20 fuel per day per coal train)

1. 12,000 tons into city (300 miles)
   - 12,000 gallons to go 470 miles→ 6817 gallons
   - @ $2.93/ gallon= $19,973.81 per day
2. 1000 tons out of city
   - 1000 gallons to go 470 miles→ 568 gallons
   - @ $2.93/ gallon= $1,664.24 per day
3. total cost of B20 for one day for 5 coal trains
   - (19973.81+1664.24) x 5= $108,190.25 per day for 5 coals trains

Case Study 2 (amount spent on B20 per day per freight train)
1. 7,000 tons into city (550 miles)
   - 7,000 gallons to go 470 miles → 7290 gallons
   - @ $2.93/ gallons = $21,359.70 per day

2. 500 tons out of city
   - 500 gallons to go 470 miles → 520 gallons
   - @ $2.93 = $1,523.60 per day

3. total cost of B20 for one day of 15 freight trains
   - (1523.60 + 21359.70) x 15 = $343,249.50 per day for 15 freight trains

Case Study 3 (Amount of PM emitted per Tier III locomotive with B20 for a round trip)
   - operational time = 20 hours
   - locomotive HP = 4500 HP

1. PM produced per hour for 1 locomotive
   - .1 gm/hp-hr x 4500 hp x 1 hr = 450 gm

2. PM produced for 1 locomotive for 20 hours
   - 450 gm x 20 hours = 9 kg

3. PM produced by 45 locomotives with B20
   - 9 kg x 45 locomotives = 405 kg x .88 = 356.4 kg PM

Case Study 4 (Amount of NOx emitted per Tier III locomotive for a round trip into/out of city)
   - Operational time = 20 hours
   - Locomotive horsepower = 4500 hp

1. PM produced per hour of running for 1 locomotive
   - PM = 5.5 gm/hp-hr x 4500 hp x 1 hr = 24,750 gm

2. PM produced for running 1 locomotive 20 hours
   - 24,750 gm x 20 = 495 kg

3. PM produced by the 45 locomotives running per day
   - 495 kg x 45 locomotives = 22,725 kg NOx emitted by 45 operating trains per day

By using Tier III locomotives, B20 fuel, and an open system catalytic reduction aftertreatment, we reduce NOx and PM emissions immensely. Tier III locomotives are 11% more fuel efficient than Tier II locomotives [4]. Therefore, these locomotives can get further on less fuel, thus reducing emissions because there is less fuel to be burned. B20 and Tier III
locomotives together reduce PM emissions by 66% [4]. The open system catalytic reduction aftertreatment reduces NOx by 70-90% [1].

GE uses 45 locomotives in their current system daily. Upgrading to Tier III costs $750,000 per locomotive which results in a cost of $33,750,000 [4]. Upgrading to B20 has no extra cost because its compatibility is included in the cost to upgrade to Tier III [4]. This as well as the fact that traditional diesel and B20 both cost the same price at $2.93 [4]. Using the open system catalytic reduction aftertreatment costs $100,000 per unit so it would cost $4.5 million for the locomotives used in a day [1][3]. Will all these costs, it would be about $38.25 million to upgrade to Tier III, use B20 fuel, and use the open systems catalytic reduction aftertreatment. However, the 11% reduction in fuel necessary because of Tier III fuel efficiency saves about $20 million each year [4]. Hence, the return on investment would be approximately 2 years. Additionally, the EPA has given a $16 million grant for environmentally friendly locomotives in the past [2]. Thus, if GE were to obtain this grant using our solution, our return on investment would be even shorter. Our solution proves to be simple and effective. Using Tier III, B20, and the aftertreatment are applications that have been used GE in the past so we know that our solution is feasible. By sticking to simplicity, our solution does not hold any extra surprises and it saves a large amount of money each year.

Design Review

During the peer review, we got many useful suggestions from the other groups. Overall, the groups liked our model. They said it was well laid out, but it would be even better if we had a physical or more visual model to further demonstrate how our specific system operates. We used this feedback to create a physical model representing the exact routes that the all of the freight is taking. Something else that was pointed out was that we should try to further reduce emissions if possible. While Tier III standards are currently acceptable, further reductions of emissions would only help the people of Boston and the smog. It was suggested to our group to further look into going to Tier IV standards despite the higher cost. In our eyes, this would yield a longer return on investment which we did not see as beneficial.
**Action Items:**

1. Look into funding to reduce the upfront cost of implementing the new system. We found out that the EPA has given a grant of $16 million for more environmentally friendly locomotives [2]. If we received this grant, or one like it, our ROI would be shortened.

2. We needed to further develop and expand our model. We created a mapped out version of the whole process to clearly show what our model is.

3. Reduce time for ROI by looking into tax breaks for Tier III or IV locomotives. If we can generate income from the new system or find a way to reduce the cost we can reduce the time for ROI.

4. Find a way to further reduce emissions by looking into making a portion of the locomotives Tier IV.

**Description of Final Design**

When choosing a final design, we agreed as a group that we needed to find the perfect balance between a large investment with great environmental benefits and a smaller investment with minimal environmental benefits. We believe we have the most environmentally beneficial design while maintaining the same amount of freight capacity and staying within the 2 year ROI.

By having all Tier III locomotives, we meet the Tier III EPA standards which are 5.5 NOx g/bhp-hr and 0.1 PM g/bhp-hr [6]. Our costs were decreased by having Tier III locomotives as they are 11% more fuel efficient than their Tier II counterparts [4]. There was no infrastructure needed after the upgrade and the aftertreatment thus our initial costs were minimized. Each locomotive cost $750,000 to upgrade from Tier II to Tier III and $100,000 for the aftertreatment [3][4]. The cost of B20 remained the same as the original diesel at $2.93 per gallon [4]. There was no change needed within the Tier III locomotives to be compatible with B20. Due to their being 45 total locomotives, our total cost came to be $38,250,000. Based off of the daily use of fuel with an 11% increase in fuel efficiency, it was calculated that the yearly savings due to this would be approximately $20,000,000 a year [4]. From this, comes our two year return of investment for GE. Due to Tier III trains being the same size as the Tier II trains, the freight capacity was unchanged while the environmental effects were bettered. Since there are no cons
to this change, public opinion would be very accepting. Also, on time delivery would remain unchanged as the speed of Tier II and Tier III locomotives remained the same.

The first part of our three prong approach being upgrading from Tier II to Tier III decreases the PM emissions by 50%. The second part of our three prong approach being the aftertreatment reduced the NOx emissions by 70-90%. The final prong of our approach was the use of B20 benefits the PM emissions by an additional 12% all of which can be seen in the graphs in Figure 6 [4].

The feasibility overall of our project is extremely high due to the fact that every part of our approach has already been successfully implemented in the past by GE. Feasibility is also increased by the fact that there is no infrastructure changes needed. The greatest aspect of our design is the pure simplicity which is also why it would be widely accepted by the public.

Figure 6. This is the physical model representation of what we plan to do including graphs on the right of the quantified environmental effects.
Figure 7. This is a simplified chart of each step of our process to get the freight from Richmond and Scranton to Boston.
Concept of Operations

Figure 8. This is the System CONOPS which is yet another visual way to show what exactly we are going to do in order to follow through with our design.

Conclusions

Our system design effectively tackles three of the major components of the emission issues in Boston: fuel efficiency, PM emissions, and NOx emissions. To combat these, our design also has three major changes to the GE locomotives: an upgrade from Tier II to Tier III, a fuel change from traditional diesel to B20, and the open system catalytic reduction aftertreatment. This design effectively tackles all three issues stated above with an 11% increase in fuel efficiency, a 66% reduction in PM emissions and a 70-90% reduction in NOx emissions [4][1]. The major pro of our design is that it utilizes existing systems and would be simple and effective for GE to implement. The major con for this system is that it does not reach
Tier IV requirements which will soon be required by the government thus requiring GE to make another upgrade in the near future once again.

There were several key points our group picked up on when doing this project. One of the most notable was the importance of practical design. When performing concept generation, it was simple to think of the most creative and innovative ideas although these were not close to practical at all. In the real world, it would take an excessive amount of time to apply a complex system such as solar powered rails or build wind turbines. To counter this though, one thing our group picked up on was that perhaps our design wasn’t ambitious enough. Although it is a practical design that met all of the requirements given, it didn’t push beyond or try to further improve the system. As a take away, the importance of having a practical design is important but true innovative design pushes boundaries to try to reach an even better solution than what was thought to be possible.
Work Cited


Other Sources


