Campus Motor Fleet Analysis for the FAA Technical Center to Meet Executive Order 13514

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***Abstract*— United States consumption of fossil fuels has been increasing at a rate of 8.4% since 1990 and is expected to grow by 28% from 2011 to 2040. *Executive Order 13514, Federal Leadership in Environmental, Energy and Economic Performance*, sets sustainability goals for federal agencies to reduce dependency on fossil fuels and decrease greenhouse gas emissions. The Federal Aviation Administration has over 4,300 registered vehicles in its motor fleet, and must reduce its emissions by 12.3% by 2020. This system provides an analysis of the life cycle costs and emissions reduction of the motor vehicle fleet at the William J. Hughes Technical Center. The analysis includes alternatives of low speed electric vehicles, neighborhood electric vehicles, and compressed natural gas vehicles. Three models are used to do analysis: (1) the demand model is a discrete-event simulation, used to determine the inventory needed to meet demand. Examples of demand events are mail delivery, and material shipping. The demand model's input is a vehicle inventory, and its outputs are metrics measuring the inventory's ability to meet demand. (2) A life cycle cost model composed of a deterministic and stochastic portions. The deterministic portion calculates preventive maintenance, overhead, and acquisition costs. The stochastic piece is a Monte Carlo simulation that projects energy consumption costs, corrective maintenance costs, and CO2 emissions through 2020. (3) A utility analysis to compare alternatives. Preliminary results indicate that the status quo inventory will not meet the requirements for GHG emission reduction. However, by reducing inventory and introducing electric vehicles, the requirements can be met while staying within current operating budgets. Based on the preliminary results, it is recommended that the FAA gradually introduce electric vehicles on an annual basis into their inventory to meet their sustainment goals by 2020.**

I. Introduction

A. Background

Greenhouse Gas (GHG) emissions deteriorate the Earth's ozone layer, leading to climate change and increases in global temperatures. GHG have been steadily increasing in the last half century, in part, due to an increase in energy demand and the exponential growth of CO2 emissions from motor vehicles. CO2 emissions comprise anywhere from 95% to 99% of greenhouse gases. The U.S. is responsible for approximately one sixth of global emissions. According to the 2012 Federal Fleet Report, the United States Government has a motor fleet of approximately 700,000 vehicles contributing to these emissions and costing them $4.4 billion a year to maintain and operate a year with fuel costs accounting for nearly a quarter of the total cost.

B. FAA

The Federal Aviation Administration (FAA) is a part of the United States Department of Transportation (DOT), with more than 48,000 employees and a 2013 budget of $15.2 billion. The Aviation Logistics Organization (ALO) is responsible for the oversight and execution of policy for all FAA campuses with regards to logistics. One of these campuses is the William J. Hughes Technical Center (ATC) in Atlantic City, New Jersey. This center provides numerous services for the FAA including test & evaluation, aviation research, systems integration, and lab services.

C. Executive Order 13514

Executive Order (E.O.) 13514 is a comprehensive list of green initiatives issued by the President of the United States, including the transition to 'green buildings', increased water conservation and recycling; as well as decreased carbon dioxide and other greenhouse gas emissions. In addition to this executive order, a General Services Administration (GSA) Bulletin, Vehicle Allocation Methodology for Agency Fleets, dated August 22, 2011, directs government agencies to apply a vehicle allocation methodology (VAM) to their fleet management when introducing more alternative vehicles to their fleets, optimizing their fleets, and conducting proper tracking and management. The decision support tool allows the FAA to comply with these government directives by providing an optimized inventory of alternatively fueled vehicles.

II. Stakeholder Analysis

A. Aviation Logistics Organization (ALO)

The ALO is responsible for implementing the most cost-effective method to achieve the transportation goals as outlined in E.O. 13514.

Objective – Develop and enforce a sustainment plan and policy to meet the requirements handed down by the DOT.

Tension – Meet the requirements of the executive order and presidential memorandum promulgated by the DOT and still be able to apportion a motor vehicle inventory to its fleet managers while staying within current budget.

B. Fleet Managers

There are fleet managers at each FAA campus who oversee the motor fleet inventory, allocate vehicles to each charge group based on need.

Objective – Provide a motor vehicle inventory for their campus capable of meeting transportation demand while staying within current budget.
Tension – Decreased fleet inventory due to optimization or budget reduction may make it not possible for vehicle users to complete all of their jobs.

C. Vehicle Users

The personnel using the vehicles on a daily basis need a sufficient number of vehicles to perform their duties. Additionally, there may be uncertainty as to whether the new alternatively fueled vehicles have the capability to meet their needs and handle the terrain and environmental conditions of the campus.
Objective – Use vehicles to accomplish work responsibilities effectively and in a timely manner.
Tension – Selected motor vehicle inventories may change the manner in which job-related tasks are completed and how soon they can be completed.

III. Problem and Need Statements

A. Problem Statement

The President has issued E. O. 13514 and a presidential memorandum which requires government agencies to reduce petroleum consumption, increase alternative fuel consumption, and optimize vehicle fleet inventories. The FAA has over 4,300 registered vehicles in its motor fleet, and by E. O. 13514 it must reduce GHG emissions from its motor vehicle fleet by 12.3% by 2020 and use only vehicles fueled by green energy sources by 2015, while continuing to meet demand within the existing budget.

B. Need Statement

The ALO needs a decision making methodology that: (1) replaces the current inventory with alternatively fueled vehicles capable of meeting transportation demand to achieve GHG emission goal, (2) calculates the total life cycle cost for the proposed inventories through the year 2020, and (3) determines a more optimized fleet inventory by eliminating underutilized vehicles. These three needs correlate directly to the system's requirements. Implementation of these inventories should allow for a "win-win" solution, minimizing the tension that exists between the fleet managers and vehicle users, as well as help the FAA carry out their mission and meet environmental mandates.

IV. Design Alternatives

Four alternatives were considered for our demand and life cycle cost analysis.

A. Gasoline

The status quo inventory is currently composed of gasoline and diesel vehicles. It is capable of meeting demand, but not the required sustainment goals. The vehicles in this inventory, leased from the GSA, have considerable CO_2 emissions and high maintenance costs.

B. LSEVs

Low speed electric vehicles (LSEVs) are battery-powered vehicles capable of speeds of up to 25 mph. LSEVs have zero direct CO_2 emissions. LSEVs are purchased instead of leased and have a comparable or lower purchase cost to gasoline vehicles, lower maintenance costs, and less overall maintenance needs, and therefore, have less downtime. There is currently no infrastructure on campus to maintain these vehicles, and as they are not street legal they cannot be maintained off campus.

C. NEVs

Neighborhood electric vehicles (NEVs) are battery-powered vehicles capable of speeds greater than 25 mph. Unlike LSEVs, they require registration when purchased and can be legally driven on neighborhood roads. These vehicles also have zero direct CO_2 emissions and are more energy efficient than the current inventory. They have maintenance procedures and costs similar to LSEVs.

D. CNGVs

Compressed natural gas vehicles (CNGVs) are vehicles modified to use compressed natural gas as a fuel source. The price of compressed natural gas is less than gasoline but it is volatile. Natural gas vehicles result in approximately 30% fewer direct CO_2 emissions than gasoline. Currently there is no fueling infrastructure available on campus for CNGVs; however, there are fueling resources within 7 miles of FAA campuses. The maintenance costs for CNG vehicles may be slightly higher due to the specialized nature of the compressed natural gas system installed.

A breakdown of alternatives and how they match up to the system requirements can be seen in Table 1.

Table 1: Design Alternatives

Does not meet requirement (red) / Meets requirement (green)		Requirements				
		Optimize Inventory	Reduce Emissions	Meet Travel Demand	Maintain or Reduce LCC	Utilization
Alternatives	Status Quo	✓	X	✓	✓	✓
	LSEVs	✓	✓	✓	✓	✓
	NEVs	✓	✓	✓	✓	✓
	Natural Gas (CNG)	✓	✓	✓	X	✓

V. Method of Analysis

A. Simulation Overview

The purpose of the simulation is to identify an inventory that meets current demand, estimates costs, and calculates CO_2 emissions. The simulation (Figure 2) is composed of three parts the demand model, the life cycle model, and the utility analysis.

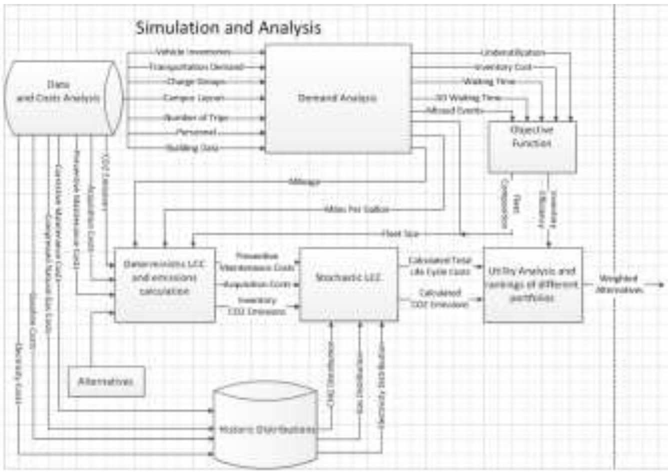

FIGURE 1: SIMULATION FLOW DIAGRAM

Table 2, below, provides a brief description of each model including the type of simulation, its purpose, and its inputs/outputs.

TABLE 2: SIMULATION DESCRIPTION

Model	Type	Program	Purpose	Input	Output
Demand	Discrete Event Queuing Simulation	Java	Predict vehicle mileage Evaluate Inventory	Inventory without mileage System Parameters	Inventory with average and standard deviation of monthly mileage
Life Cycle Cost	Monte Carlo Simulation	Excel	Estimate Inventory LCC	Inventory with mileage	Inventory cost of different alternatives CO2 emissions
Utility Analysis	Discrete Calculation	Excel	Evaluate Alternatives	Inventory metrics and cost	Weighted comparison between alternatives and graph

The Technical Center organizes personnel into charge groups aligned to each of the areas they support. There are seven charge groups for this analysis: #1 is lab services, #2 is aviation research, #3 is center operations, #4 is research & development management, #5 is air traffic systems test & evaluation, #6 is enterprise test & evaluation, #7 is technical strategies and integration. Each charge group is allotted vehicles from the overall inventory to execute tasks. The demand model simulates one year of events. Based on the inventory performance metrics, alternative inventories are created by analyzing underutilized vehicles then eliminating or redistributing them to a different charge group. Alternative inventory's outputted mileage is used by the life cycle cost model. For convenience of programming the models, the CO_2 emissions for the new inventories are calculated for all alternatives as part of the LCC model. The utility analysis then compares the alternatives based on the efficiency of the inventory and CO_2 emissions. This analysis is used in concert with the cost analysis to determine the recommendation for an alternative vehicle fleet.

B. *Design of Experiment*

1) *The Demand Model*

The demand model takes in campus parameters derived from historic campus data, which is used to generate a monthly demand and a vehicle inventory that contains information such as: charge group, vehicle type, and miles per gallon to meet the generated demand. The demand model's outputs are the inventory performance metrics, which are analyzed to make adjustments to the inventory, and each vehicle's average monthly mileage.

The model generates arrival events that are serviced by vehicles with the event's required charge group and vehicle type. If there is not a matching available vehicle, then the event is added to a queue where it awaits service until a maximum of 45 minutes. If the vehicle is not serviced in 45 minutes, the simulation records a missed event and assumes the demand no longer exists. These runtime routines are run throughout the course of a ten-hour workday, and then aggregated into daily and monthly data. The output is then used to calculate estimated energy consumption for each fuel alternative in the LCC.

a) *Demand Model Grid*

The accuracy of the average monthly mileage output of the demand model is highly affected by the grid, as represented in Figure 3. The distance and the probability of the distance are derived from the position of the charge codes on the grid. For example, there is a high probability that grid 6 will have a shorter travel distance than charge group 4. Figure 3 shows the locations of the charge codes on the grid.

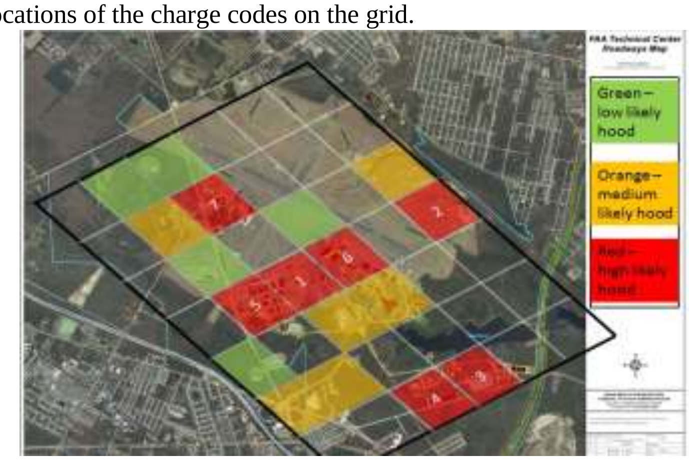

FIGURE 3: WILLIAM J. HUGHES CAMPUS GRID REPRESENTATION

2) *Objective Function*

An objective function compares different inventory compositions by calculating inventory costs, as given below.

$$Min\ z = \sum(Cu_i + Cu_i) + Cw + SDw + Cm \qquad (1)$$

TABLE 3: OBJECTIVE FUNCTION PARAMETERS

Categories	Definition
Utilization (Cu)	Emphasis on percentage of vehicles being used at any time being at or around 85%.

Inventory Size (Ci)	Emphasis on reducing the amount of vehicles in the fleet (i.e. smaller than status quo)
Total Wait Time (daily) (Cw)	Emphasis on reductions in average time spent waiting for a vehicle to become available in a day.
Standard Deviation of Wait Time (SDw)	Emphasis on fairly consistent wait-times.
Missed Events (Cm)	Emphasis on reducing number of events that do not get serviced within 45 minutes of demand arrival.

A constraint of 5 average missed events per day was placed on alternative inventories. The top 5% inventories with respect to the objective function costs were input in the LCC model. By calculating an inventory's objective function costs, the status quo inventory can be optimized among a set of chosen inventories. The same objective function parameters were used in the utility analysis using the stakeholder's input.

3) Life Cycle Cost Model

The LCC model is a Monte Carlo simulation composed of deterministic and stochastic components. The deterministic portion of the LCC model includes acquisition, infrastructure, and preventive maintenance costs of the vehicles. The deterministic costs are determined by fleet size, LCC period, and fuel alternative. A LCC period of 6 years was chosen because of the Executive Order requirements. For the acquisition segment, data regarding the leasing costs of current inventory from GSA, the purchasing costs of LSEV, NEV and CNG options were used. In calculating infrastructure costs, no additional costs regarding fueling infrastructure for gasoline or CNG vehicles were taken into account; however, for electric vehicles, costs of charging stations and their installation were included. Preventative maintenance, such as brake pad replacement, was calculated based on the duration of the LCC simulation.

a) Stochastic Calculations

Each vehicle's mileage and each month's energy cost and corrective maintenance was randomly generated from their respective distributions. To model corrective maintenance (repairs), a lognormal distribution of maintenance costs, derived from data concerning a similar vehicle fleet at George Mason University, was applied to the Technical Center fleet. Each month the LCC generates a normally distributed monthly mileage per vehicle using the vehicle's average and standard deviation. The model derives monthly fuel usage which is multiplied by the month's randomly generated fuel price.

VI. Energy Price Forecasting

A geometric Brownian motion with drift was used to model stochastic price changes over time of gasoline, compressed natural gas and residential electricity. The differential form is given below.

$$dS_t = uS_t\,dt + \sigma S_t\,dW_t \qquad (2)$$

The annualized percent drift, u, was calculated from expected price increases in the "Life-Cycle Costing Manual for Federal Energy Management Program". The percentage volatility, σ, was calculated from historic data distributed by the EIA. The figure below shows 300 gasoline prices after 6 years.

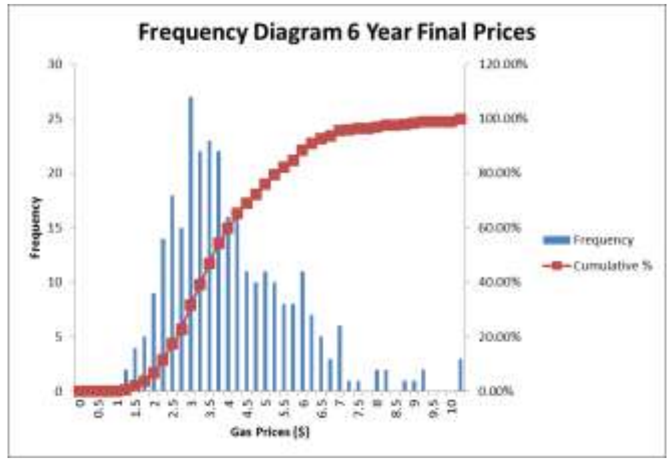

FIGURE 4: FORECASTED 6 YEAR GASOLINE FUEL PRICES

1) The Utility Analysis

The inventory alternatives plugged into the simulation were ultimately evaluated against one another based on a utility analysis whose hierarchy can be seen below in Figure 3.

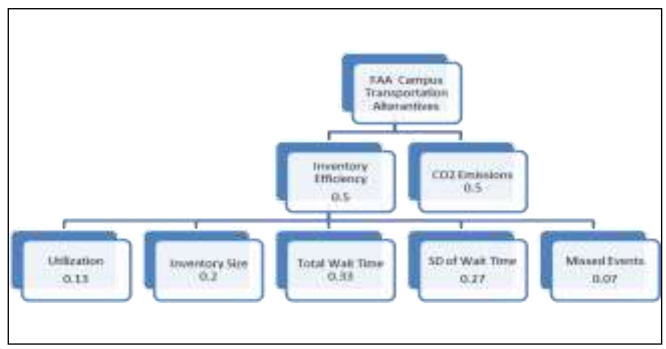

FIGURE 5: VALUE HIERARCHY

There are two main categories of "Inventory Efficiency" and "CO_2 Emissions" used to weigh alternatives with respect to our stakeholders. The weights for the subcategories under "Inventory Efficiency" were determined through survey and discussions with seven stakeholders.

VII. Results

A. Status Quo Comparisons and Verification

As seen in Figure 6, the output of the demand model is similar to the historical data. The output of the simulation was compared to the historical average of the miles driven per month minus twenty percent. The largest disparities between the historical data and the simulation output were the tails. The Demand Model output had a more positive skew than that of the historical data.

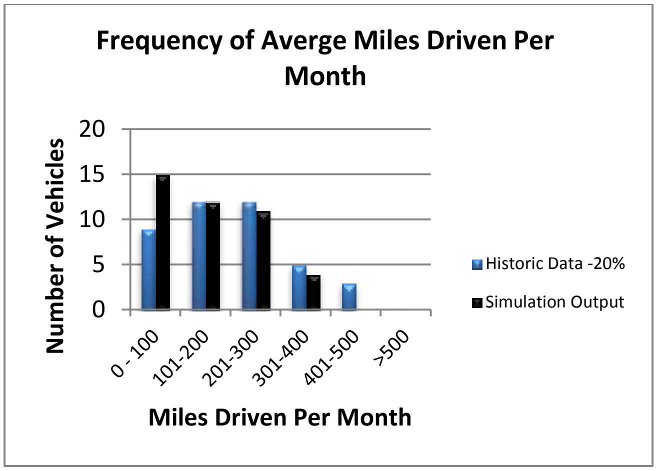

FIGURE 6: SIMULATION VERIFICATION RESULTS, 1000 REPLICATIONS

The difference between the 0-100 and 401-500 bins can be explained by off campus mileage. Off campus demand is not being taken into account, the model compensates for off campus mileage with short distance, on campus trips.

B. Comparisons when Inventory is Randomized

The simulation was also run with the inventory randomized after every month. The original version of the simulation randomized the inventory but the histograms (Figure 7) did not resemble each other and the results were undesirable for verification purposes. As can be seen by comparing Figure 6 to Figure 7, the nonrandomized inventory more closely resembles historic data.

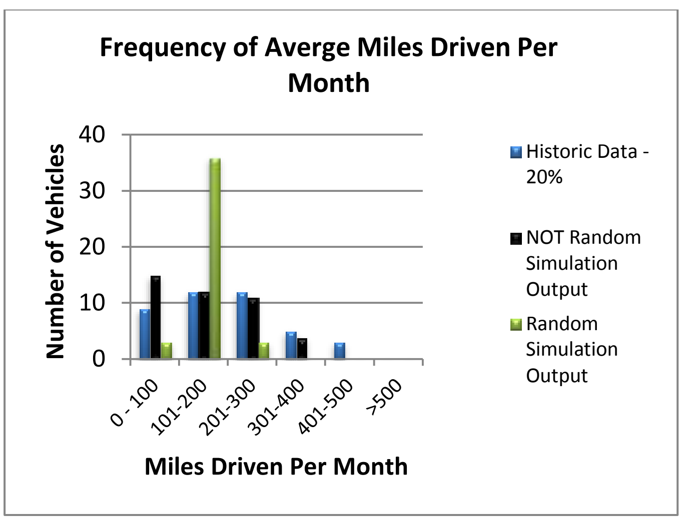

FIGURE 7: RANDOMIZED INVENTORY HISTOGRAM

C. Objective Function

There were approximately twenty inventories ranging in size from 38 to 42 vehicles originally run. Four inventories were chosen based on the number of missed events per day found in the demand model. Those four inventories demonstrated the highest, lowest and closest missed event times to that of the status quo. The status quo had 42 vehicles, of which 8 were administrative. All inventories had 8 or less administrative vehicles so as to maintain practicality. While operational vehicles could have met administrative demand they were considered strictly operational to facilitate testing. It was determined from the division descriptions, that charge codes 4, 7 and 2 were administrative making charge codes 1, 3, 5 and 6 solely operational. Inventories consisting of charge codes containing both administrative and operational vehicles were tested, but yielded much larger average daily missed events reaching double digits. All inventories were run for 2000 replications. Their size, idle time, total cost, average wait time and missed events can be viewed in the table below (Table 4).

TABLE 4: INVENTORY PARAMETERS

Inventory Name	Size	Underutilization (min)	Total Cost ($)	Avg. Missed Events/day	Avg. Wait Time/day
Status Quo	42	122	18112.76	.76	170
Inventory A	41	119	19545.69	0.944	196.69
Inventory B	39	114	22536.96	1.155	259.89
Inventory C	41	121	19136.79	0.994	195.52
Inventory D	41	119	18822.23	0.784	185.86

While the results indicate that the removal of just one vehicle in the inventory increases the average daily missed events, in this case by an average of 0.14. Inventories not chosen showed similar results as there appeared to be a trend between smaller inventory size and larger average waiting times and missed events per day. All proposed alternatives had lower underutilization times than the status quo and all fuel alternatives had lower CO2 emissions than the current gasoline fleet, as seen in Figure 8.

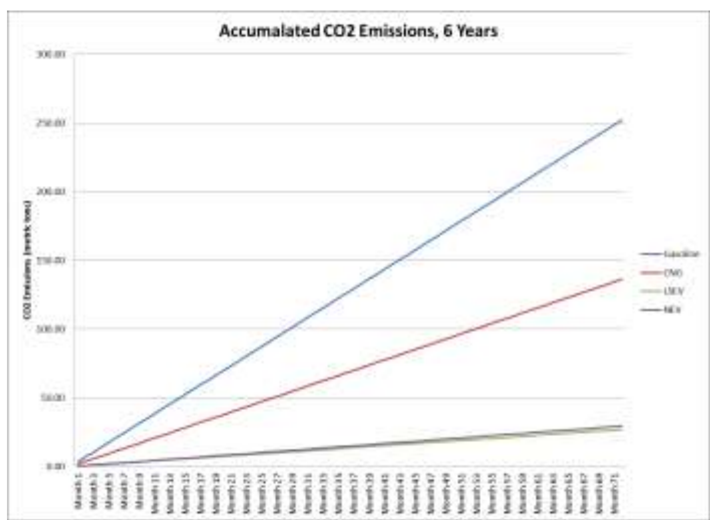

FIGURE 8: CO2 EMISSIONS PROJECTIONS

Utility analysis of the alternative inventories based on the previously mentioned value hierarchy yielded a utility of 0.335, 0.290, 0.165, 0.290, and 0.332 for the status quo, inventory A, B, C and D respectively in regards to the category inventory efficiency. A six year LCC analysis was performed on the status quo sized inventory, composed of only CNG's, LSEV's or NEV's. CNG inventories were the most expensive because of their corrective maintenance and acquisition costs, followed by gasoline because of its energy costs, lastly the electric vehicles had the lowest 6 year life cycle cost. Figure 9 shows the cost versus utility of the status quo inventory with each fuel alternative.

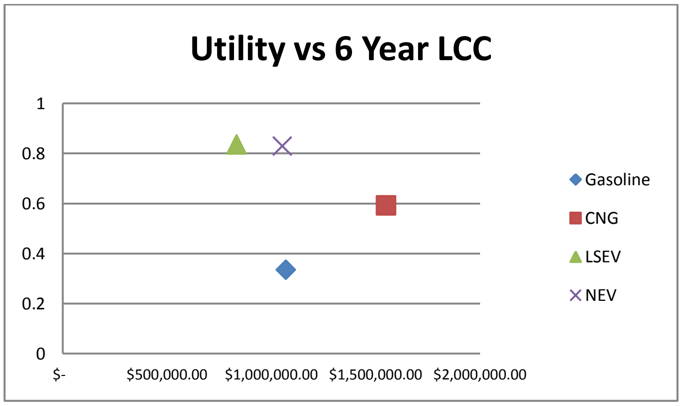

FIGURE 9: UTILITY VS COST

VIII. RECOMMENDATIONS AND CONCLUSIONS

Recommendations based on our analysis and research:

1. The Executive Order GHG emissions target of 12.3% can be met by each fuel alternative except by the current gasoline inventory, CNG by 46%, NEVs by 88%, LSEVs by 89%.
2. NEVs and LSEVs are financially feasible with lower six year costs then the current inventory. CNG fueled vehicles are more expensive and take a much longer life cycle before a return on investment is gained.
    a. Electric vehicles reduce the variability of LCC due to more stable energy costs.
3. Analysis of the demand model shows that it would be possible to reduce the size of the fleet, if care is taken with which charge codes are affected.
    a. A decentralized fleet with a motor pool is effective at reducing inventory size while minimizing the bottlenecks of smaller inventories
    b. Inventory utilization does not directly correlate to queue size, waiting times, or missed events.

ACKNOWLEDGMENT

We wish to acknowledge the special contributions of Mrs. Paula Lewis, Ms. Karen Kirk, Ms. Laura Sullivan, Dr. Lance Sherry, Dr. Peggy Brouse, Dr. Jie Xu, Dr. Rajesh Ganesan, Dr. Bjorn Berg, Dr. K. C. Chang and Dr. Karla Hoffman.

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