DECISION MAKING MODEL FOR THE MANAGEMENT OF TRANSIT SYSTEM ALTERNATE FUEL INFRASTRUCTURES THROUGH THE UTILIZATION OF AN INTERACTIVE EXPERT SYSTEMS INTERFACE

by

Michael L. Vaughan

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Civil Engineering

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DEDICATION

To my beloved mother and father,

The late Mrs. Gwendolyn E. Vaughan and the Rev. Dr. Sammy C. Vaughan.

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ABSTRACT

There are many factors in the decision making process which, when taken into account, lend themselves to a reasonable fleet management approach that is both robust and sustainable in a dynamic and technologically rich environment. The work in this area falls under the general area of Transportation Engineering with a more broad connection to Civil Engineering.

Traditionally, the process used by public transportation entities to determine the acquisition strategy for new vehicle asset is based upon a broad range of criteria. Vehicle cost has been cited as one of the more critical factors which decision makers consider. It is currently a common practice to consider other factors that contribute to a more comprehensive approach. Some of these other factors are as follows:

1. life-cycle cost, fuel efficiency
2. Vehicle reliability
3. Environmental effects

Although federal agencies, e.g. Federal Transit Administration (FTA), have published several reports investigating and comparing alternative fuel buses, those reports do not directly suggest which technology is a dominant choice for a specific state. (Shahpar, 2010)

The determination of the most appropriate alternative fuel bus asset for a given application is not necessarily that straight forward. The typical bus fleet is developed over a broad time horizon with each asset being acquired to meet a certain agency need or to close a perceived gap in the delivery of public transportation service. Therefore; as new assets are considered, it is critical for the fleet manager to consider as many factors of the fleet infrastructure to better ensure the positive impact that the newly acquired asset will have on fleet performance relative to the overall service goals and objectives of the fleet.

This study investigates a broad range of alternative-fuel bus technologies and the associated factors that will inform the decision making process. Further, this work utilizes the inventory and understanding of the range of technology factors and leverages the perspective (knowledge) of industry experts on each of these factors to develop an expert systems decision making philosophy to aid in the adoption of industry standards, best practices, consistency and sustainability in fleet asset management over time.

This study investigates what I believe is the next generation of advancements in decision making tools in the area of the application of methods to quantify and manage uncertainty. In particular, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes. The fleet decision making process in most governmental agencies is a very complex and interdependent activity. There are always competing forces and agendas within the view of the decision maker. Rarely is the decision maker a single person although, within the transit environment, there is often one person charged with the responsibility of fleet management.

The focus of this research examines the decision making of the general transit agency community via the development of an expert systems prototype tool based upon the Exsys Corvid® software platform. The platform has been selected for its broad capability in capturing expert decision making knowledge and data in an easy to understand user applicable format.

A computer-based prototype system is developed, within the Exsys Corvid® environment, which provide an expert knowledge-based recommendation, based upon variable user inputs. The results shown in this study show that a decision making tool for the management of transit system alternate fuel vehicle assets can be modeled and tested.

The direct user of this research are the transit agency administrations. The results can be used by the management teams as a reliable input to inform their urban transit buses expansion decision making process.

Chapter 1

INTRODUCTION

1.1 Background

Given the economic, energy and environmental landscape of the 21st century and beyond, many municipal transit agencies must utilize informed decision making to project the scope and characteristics of future fleet asset acquisition.

In the past two decades, transportation emissions increased by nearly 20 percent due, in large part, to increased demand for travel and static levels of fuel efficiency across the U.S. vehicle fleet. At the same time, the number of vehicle miles traveled by light-duty motor vehicles (passenger cars and light-duty trucks) increased 34 percent, as a result of a host of factors including population growth, economic growth, urban sprawl, and low fuel prices over much of this period.

With accelerated growth, public transportation use can do much more to support this nation's progress to energy independence while reducing the carbon footprint from the transportation sector. More than 10.3 billion trips are taken yearly on public transportation in the United States. It is possible to reduce this nation's oil consumption and carbon footprint substantially via the adoption of a disciplined strategy of public transportation utilization. Establishing a goal to put in place high-quality, high capacity, energy-efficient and environmentally responsible public transportation systems in every metropolitan area in America is essential. (American Public Transportation Association – Discussion Paper, 2008)

These high-quality, high capacity, energy-efficient and environmentally responsible public transportation systems are within the solution space provided by alternative fuel vehicles. It is important to consider the process of how a municipality or public transportation agency would conduct an evaluation of the most suitable alternative fuel vehicles for their needs. There are various factors which will determine the acquisition strategy for a given entity. This work focuses on a novel process to assist fleet decision-makers in approaching this determination by leveraging the growing knowledge base of experts within the realm of alternative fuel vehicle technologies.

1.2 Problem Statement

Traditionally, the process used by public transportation entities to determine the acquisition strategy for new vehicle asset is based upon a broad range of criteria. Vehicle cost has been cited as one of the more critical factors which decision makers consider. It is currently a common practice to consider other factors that contribute to a more comprehensive approach. Some of these other factors are as follows:

1. life-cycle cost, fuel efficiency
2. Vehicle reliability
3. Environmental effects

Although federal agencies, e.g. Federal Transit Administration (FTA), have published several reports investigating and comparing alternative fuel buses, those reports do not directly suggest which technology is a dominant choice for a specific state. (Shahpar, 2010)

The determination of the most appropriate alternative fuel bus asset for a given application is not necessarily that straight forward. The typical bus fleet is developed over a broad time horizon with each asset being acquired to meet a certain agency need or to close a perceived gap in the delivery of public transportation service. Therefore; as new assets are considered, it is critical for the fleet manager to consider as many factors of the fleet infrastructure to better ensure the positive impact that the newly acquired asset will have on fleet performance relative to the overall service goals and objectives of the fleet.

1.3 Purpose and Objectives

This research investigates a broad range of alternative-fuel bus technologies and the associated attributes that will inform the decision making process. This research leverages the inventory and understanding of the range of technology factors and leverages the perspective of industry experts on each of these factors to develop an expert systems decision making resource to aid in the adoption of industry standards, best practices, consistency and sustainability in fleet asset management over time.

This investigation includes, transit system industry review, industry expert survey instrument creation, expert data extraction and analysis, expert system development and other related factors.

1.4 Scope

The direct user of this research are the transit agency administrations. The results can be used by the management teams as a reliable input to inform their urban transit buses expansion decision making process. This research does not cover paratransit vehicles.

The results of this study are valid under the following assumptions (Shahpar, 2010):

- The bus useful life is 12 years.
- The buses are all 40-ft in length, low floor designs, without elaborate equipment specifications.
- The buses are operated at average national conditions, speed of 12.5 mph and annual mileage of 35,000.
- When B20 biodiesel is used, the whole depot is converted, and additional, separate, fuel tanks are not required.
- Driver and mechanic training costs are not considered, but mechanic time is considered in maintenance costs.
- Driver operational costs are not considered.
- Benefits such as emissions credits, fuel tax credit or subsidies for having alternative technology vehicles are not considered.
- 80 percent federal subsidy for bus procurement was considered.
- The maintenance costs are constant (in 2009 dollar terms) for the 12 year life, and all data are presented as 2009 dollars.
- The fuel prices are constant (in 2009 dollar terms) for 12 years as follows: 1) 3.33 ($/gal) for ultra-low-sulfur diesel, 2) 3.40 ($/gal) for biodiesel, 3) 1.91 ($/gal) for CNG.

1.5 Organization of the Dissertation

The focus of this research is the development of a decision making tool with the potential to greatly impact the method in which overall transit infrastructures are managed. Therefore, this research investigates technologies that lend themselves to new and exciting applications in the acquisition, management and operation of transit infrastructure systems as well as investigations involving the methods and paradigms that allow these technologies to inform the overall Transportation Engineering infrastructure asset management process.

To facilitate the objective of this study, the sections of the dissertation are organized in the following manner:

- Chapter 1 provides an introduction to this study and the decision making prototype strategy made possible through the use of the Exsys Corvid® prototype environment.
- Chapter 2 provides an analysis of the Argonne Report and the Shahpar Thesis. The Argonne Report showed that the commercial intracity truck industry would be an area for serious consideration to take advantage of the benefits of NG technologies; where this could be achieved with the demonstration of a long-term aggressive future market penetration of heavy-duty NG vehicles. The Shahpar Thesis showed that hybrid diesel-electric buses rate well according to the criteria of energy, environmental impact, industrial relationship, and implementation cost for DART (Shahpar, 2010). Shahpar found that capital cost varies based upon facilities that transit agencies already have in place and the best purchase option

may change based upon the scope of the bus procurement; where, LCC is sensitive to the number of buses that will be purchased.

- Chapter 3 presents information on the USDOT Fuel Cell Bus Program: Alameda-Contra Costa Transit District (AC Transit) and the importance of fleet testing to inform future recommendations for fleet manager decision making under certain fleet conditions. The chapter highlights the overall thought processes of this organization as it attempted to align itself with this national demonstration effort. The operating data for the early evaluation of these prototype fuel cell buses showed that the implementation was reasonably successful.
- Chapter 4 provides an overview of decision making tools which focus on the concept of Life Cycle Assessment. This chapter also provides a broad overview of the field of artificial intelligence (AI) and the AI sub-field of knowledge-based expert systems (KBES). These technologies have proven useful in providing a foundation for the development of the prototype decision making system described in this dissertation.
- Chapter 5 provides a perspective on the notion of uncertainty in decision making processes and highlights a study which suggested that alternative bus technology holds great promise for cities, and by extension, municipalities and other governmental transit agencies; which have interest in meeting very rigorous emissions reduction targets. This study showed the uncertainty that exists in the decision making process for alternative fuel buses.

- Chapter 6 presents work of on uncertainty in fuel availability where it is possible to define design parameters to help policy makers develop a better understanding of the impact of their decisions given real-world uncertainties in technology innovation and market changes.
- Chapter 7 provides important information regarding uncertainty in fuel pricing based upon the volatility in the global fuel market due to a wide range of independent factors and variables; where, alternative fuel prices fluctuate greatly per gallon relative to conventional fuels and pricing fluctuations are impacted by many factors, including actual price changes as a result of global supply dynamics, the price sampling methodology by both location and fuel quantity, and seasonal demand.
- Chapter 8 presents the concept of "cradle to grave" comprehensive analysis as related to alternative fuels which involves a broad spectrum of environmental factors and/or attributes which can be associated with products and services in order to support process development, influence policy and promote informed decision making.
- Chapter 9 presents the analysis of studies on improvements in methods of analysis to enable better design and decision making in fleet use of alternative fuel technologies; where, the management of uncertainty within the decision making process is very important to better ensure decision quality.
- Chapter 10 describes an approach to develop a prototype decision making system for the use in fleet management applications. Further, this decision making

prototype models the interdependency of factors shown as important to the decision making process to assist the bus fleet manager with Alternate Fuel Vehicle (AFV) technologies.

- Chapter 11 presents the Exsys Corvid® development environment which was utilized for the KBES prototype process. Exsys Corvid is a powerful tool for developing interactive expert system applications in a web-based format (Exsys Inc., 2016). This chapter also presents the user interface query design for the Exsys Corvid® based prototype decision making tool based upon fleet characteristics, criteria and impact index (Y) as derived from the Shahpar expert survey data.
- Chapter 12 provides summary, conclusions and future recommendations for continued work.

1.6 Methodology

In the work by (Shahpar, 2010), the focus was to provide DART (Delaware Authority for Regional Transit) administrative decision making support relative to its future fleet expansion processes.

The focus of this research will expand these concepts to inform the decision making of the general transit agency community via the development of an expert systems resource based upon the Exsys Corvid® software platform. The platform has been selected for its broad capability in capturing expert decision making knowledge and data in an easy to understand user applicable format.

Exsys Corvid® Expert System Development Tool

Exsys Corvid® is a powerful and extensively proven tool for building and fielding interactive expert system applications online. It is designed to be easy to learn and aimed at non-programmers. It enables the decision making logic and process of the domain expert to be converted into a structured form that can be used by the Exsys Inference Engine to dynamically drive interactive sessions that provide advice to end users (Exsys Inc., 2016).

For background and information, the following database and reports (and others) will serve as a basis for investigation in this area and to inform the creation and development of the expert survey instrument by defining the overall scope of the necessary variables for consideration:

APTA Public Transportation Vehicle Database (APTA, 2013)

The Public Transportation Vehicle Database is an annual report of revenue vehicles by fleet characteristics, including date of manufacture, manufacturer, model, length, and equipment for approximately 250 U.S. transit agencies and 15 Canadian transit agencies. It includes summary tables which group vehicles by mode and list by manufacturer, size, year built, and equipment. A special section on the new vehicle market includes orders, planned orders, prior year deliveries, and vehicle costs. Reports are published annually in June. Available in Adobe PDF, Microsoft Access and Microsoft Excel formats.

APTA Passenger Characteristics Report (APTA, 2007)

An analysis of transit passenger demographic and travel characteristics is presented in APTA's Profile of Public Transportation Passenger Demographics and Travel Characteristics Reported in On-Board Surveys. Public transportation agencies conduct on-board surveys of their riders on a recurring, but often infrequent, basis. The surveys are important for local transportation planning and marketing purposes. Knowledge of who transit customers are and how they travel is essential for tailoring transit service to meet each community's needs.

Center for Neighborhood Technology Report (CNT, 2010)

This report identifies a portfolio of strategies that transit agencies can take to reduce the energy use and Green House Gas (GHG) emissions of their operations and estimates the potential impacts of those strategies in 2030 and 2050. As transit agencies respond to the call to action presented by these climate action plans by expanding service, they face the coincident challenge of reducing their own operational emissions.

1.7 Originality of this Work

In order to demonstrate the feasibility of the development of a decision making tool to aid and inform the decisions of the fleet manager regarding Alternate Fuel Vehicles (AFV), this research presents a prototype which models the interdependency of factors shown as important to the decision making process. In the work by Shahpar (Shahpar, 2010), the focus was to provide DART (Delaware Authority for Regional Transit) administration decision making support relative to its future fleet expansion processes. The focus of the research for this dissertation expands these concepts to inform the decision making of the general transit agency community via the development of a prototype expert systems resource based upon the Exsys Corvid® software platform. This platform has been selected for its broad capability in capturing expert decision making data in and easy to understand user applicable format.

This Exsys Corvid® based prototype system can assist users in finding the appropriate alternative fuel bus that aligns with the desired fleet parameters and performance characteristics. The system recommends a good fleet asset choice based upon a number of industry expert-derived life-cycle and performance factors.

Chapter 2

ANALYSIS OF THE ARGONNE REPORT AND SHAHPAR THESIS

The analysis of the Argonne Report (Argonne National Laboratory, 2010) and the Shahpar Thesis (Shahpar, 2010) was an important step in the development of the broad concepts in this dissertation. Both of these studies provided a clear methodology for the following:

1. Investigation of alternative-fuel technologies for positive societal impact
2. Focus on environmentally friendly alternatives in addition to cost benefit
3. Correlation of the use of these AFV (Alternate Fuel Vehicle) technologies and the application to fleet use in order to harness the benefit of use from the scalability potential through fleet volume.

These studies provided good background information and support for the overarching conceptual assertions under investigation in this research; where it is proposed that the next generation of advancements in decision making tools in the area of the application of methods to quantify and manage uncertainty. In particular, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes. Since the focus of this research examines the decision making of the general transit agency community, the Argonne Report and the Shahpar Thesis were useful in highlighting two very distinct but comparable approaches to understand the alternate fuel decision making environment.

Argonne Report

The Argonne (Argonne National Laboratory, 2010) report begins with a basic inference that the recent United States shale gas discoveries have been one of the primary factors in the heightened interest in using natural gas (NG) as a fleet vehicle fuel. Further, it was cited that NG vehicle use has continued to grow outside the United States for the past decade. This study references the U.S. Department of Energy's Clean Cities Program Report. Clean cities is a public-private partnership which advocates for the energy, economic, and environmental security of the U.S. via support local decisions that reduce transportation sector petroleum use. The Clean Cities Program Report informed the author's understanding of the state of natural gas vehicle technology and overall life-cycle cost -- and its relationship with the prevailing European natural gas vehicle technologies, latest research and development efforts, and current market barriers and opportunities for greater market penetration.

This study suggested that the commercial intracity truck industry would be an area for serious consideration to take advantage of the benefits of NG technologies. Further, the study found that this can only be achieved with the demonstration of a long-term aggressive future market penetration of heavy-duty NG vehicles. To support this perspective, the study employed Energy Information Administration projections and GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) life-cycle modeling of U.S. on-road heavy-duty use NG vehicles. This study found that on-road heavy-duty petroleum consumption reductions of approximately 1.2 million barrels of oil per day and the reduction of another 400,000 barrels of oil per day reduction, through the use of NG off-road vehicles, could be achieved. In conclusion, the study found that this shift in the United States industry to NG vehicle usage has the potential for an 8% reduction in daily oil consumption.

Shahpar Thesis

The work of Shahpar (Shahpar, 2010) suggested that the Energy Policy Act of 1992 was a primary catalyst for United States governmental transit agencies to use alternative-fuel transit buses to enhance their existing diesel bus fleets. Although this statement may be indicative of a nationwide governmental shift, Shahpar's work focused on the development of a decision making tool to aid the fleet decision making strategy of the Delaware Authority for Regional Transit (DART).

The work of Shahpar was informed by reports published by:

1. Federal Transit Administration (FTA)
2. Transit Cooperative Research Program (TCRP)
3. National Renewable Energy Laboratory (NREL)
4. United States Environmental Protection Agency (EPA)

In addition to knowledge and insights Shahpar acquired via participation in two major conferences related to public transportation:

1. BusCon 2009 in Chicago, Illinois
2. APTA annual meeting 2009 in Orlando, FL.

Of the eight distinct alternative-fuel bus technologies captured in the Energy Policy Act of 1992, this work found that only three technologies are "viable alternatives" for the Ultra-Low Sulfur Diesel (ULSD) transit buses due to Life-Cycle Cost (LCC) and emissions estimates. As a result, this study focuses on the following alternative-fuel technologies:

1. Compressed Natural Gas (CNG)
2. Biodiesel
3. hybrid-diesel

Generally, LCC includes capital cost and operating cost. Shahpar defined these costs within his study and determined that hybrid-diesel buses have the lowest overall LCC, a parameter defined as $/mile. Further, this study provided a rank analysis for these four technologies for both capital and operating costs, where the rankings for capital were:

1. ULSD
2. Biodiesel
3. Hybrid diesel-electric
4. CNG

and the rankings for operating cost were:

1. CNG
2. Hybrid diesel-electric
3. ULSD
4. Biodiesel

It was found that while all alternative-fuel buses meet or exceed EPA emissions standards, recent data suggests that hybrid diesel-electric buses are the most environmentally friendly. This study extended this benefit to suggest that hybrid diesel-electric buses are the most suitable alternative-fuel buses for DART deployment.

The remaining portion of this study was devoted to the development of an expert systems technology tool to assist DART with fleet decision making. In summary, Shahpar defined an expert survey instrument to extract important decision making knowledge and data from experts in various organizations within the government, bus manufacturing industry, academe, energy sector, and independent research environments.

Shahpar concluded that hybrid diesel-electric buses rate well according to the criteria of energy, environmental impact, industrial relationship, and implementation cost for DART. The Overall results of this study suggest that each transit agency consider its unique situation and infrastructure before determining what alternative-fuel bus technology provides the most benefit and value. Shahpar supported his conclusion with the following:

1. Capital cost varies based upon facilities that transit agencies already have in place
2. Within a given transit agency, the best option may change based upon the scope of the bus procurement, where LCC is sensitive to the number of buses that will be purchased.

Shahpar suggested that transit agencies use other transit agencies experience and/or studies, such as this this work, to perform their own local evaluation.

2.1 Comparison of the Argonne Report and the Shahpar Thesis

There are many similarities and differences that can be cited between the Argonne Report (Argonne National Laboratory) and the A. Shahpar Thesis (University of Delaware). For the scope of this analysis, an attempt will be made to cite just three similarities and three differences that perhaps highlight a broad perspective to compare and contrast these studies. Both of these efforts are contemporary in nature and were conducted in the 2010 timeframe. This fact is helpful relative to the general research findings available at that time to the studies. Below are the similarities between these studies that will be addressed:

2.1.1 Similarities:

1. Investigation of alternative-fuel technologies for positive societal impact
2. Focus on environmentally friendly alternatives in addition to cost benefit
3. Correlation of the use of these AFV (Alternate Fuel Vehicle) technologies and the application to fleet use in order to harness the benefit of use from the scalability potential through fleet volume.

Both the Argonne Report and the Shahpar Thesis have at their center an interest in the investigation of alternative-fuel technologies for positive societal impact. This is evidenced in the rationale given in each of the studies as to the importance of this work in addressing an existing societal condition. Societal impact is a very broad construct but if one is to provide context to the Argonne Report and the work by Shahpar around societal impact, then a framework for measuring this impact would be useful. The work of (Roche et al, 2010) provided one approach in this regard and offered an overview of a conceptual framework and methodology, where four approaches are distinguished: general attitudinal surveys, risk perception studies, non-market economic valuation studies, and other approaches such as those based on semiotic theory; which is the study of or theoretic use of signs and symbols as a portion of a communications strategy. Further, this work reviewed literature on acceptance, attitudes and preferences for hydrogen and fuel cell end-use technologies, focusing on vehicles. These studies were then contrasted with related research into alternative fuel vehicles.

At the root of the Argonne and Shahpar studies is the fundamental belief that these enabling technologies, when applied appropriately, can provide tangible value and benefit to society. Further, it was postulated that these realized benefits have the potential to be vast and sustainable. The impacts of the recession on public transportation systems have been more severe than other transportation modes because these systems are mainly supported by State funds which have declined (Shahpar, 2010). Clearly, the immediate economic benefit and budget impact alone are compelling reasons for this investigation but when coupled with other efficiencies in Life-Cycle Cost and overall environmental emissions reductions, the long term benefits of this work is quite evident.

The Argonne Report found that increased use of natural gas vehicles has the potential to substantially reduce petroleum consumption. The study contended that commercial intracity trucks are a prime area for the advancement of this fuel. The study examined an aggressive future market penetration of natural gas heavy-duty vehicles. The study found that by using Energy Information Administration projections and GREET life-cycle modeling of U.S. on-road heavy-duty use, natural gas vehicles would decrease petroleum consumption by an estimated 1.2 million barrels of oil per day, while another 400,000 barrels of oil per day savings could be realized with significant use of natural gas off-road vehicles. This scenario would reduce daily oil consumption in the United States by about 8% (Argonne, 2010). Beyond the economic benefit offered by this technology is potential positive environmental impact, as well as, the potential for pushing the needle of US energy independence in the desired direction.

Below are the differences between these studies:

2.1.2 Differences:

1. The diversity of alternate-fuel technologies under consideration
2. Focus on a local governmental decision making solution vs. a more generalized approach applicable to many environments
3. The integration of expert system technology to enhance the analysis within the work and to inform the understanding of other independent reports and studies

The Argonne Report and the Shahpar Thesis have clear differences in scope, approach, observations and conclusions. The Shahpar Thesis used a basic approach to investigate a diversity of technologies to determine the Life Cycle Cost (LCC) and emissions characteristics that are important to the decision making process. LCC includes capital cost and operating cost and Shahpar defined these costs within the study and determined that hybrid-diesel buses have the lowest overall LCC, a parameter defined as $/mile. Further, Shahpar narrowed his investigation from eight to three technologies where a rank analysis for these three technologies was performed for both capital and operating costs, with the following rank results: 1) ULSD (Ultra Low Sulfur Diesel), 2) Biodiesel, 3) Hybrid diesel-electric, and 4) CNG (Compressed Natural Gas) and 1) CNG, 2) Hybrid diesel-electric, 3) ULSD, and 4) Biodiesel, respectively. Shahpar showed that while all alternative-fuel buses meet or exceed EPA emissions standards, data suggests that hybrid diesel-electric buses are the most environmentally friendly. Shahpar's work extended this benefit to suggest that hybrid diesel-electric buses are the most suitable alternative-fuel buses for DART deployment. It is clear that this approach is conducive to the broad conclusions that Shahpar offered in the specific DART decision making process and, subsequently, the more generalized case. The Argonne Report focused on the impact that recent United States shale gas discoveries have on the heightened interest in using natural gas (NG) as a fleet vehicle fuel. Further, the report suggests that the US may have fallen a bit behind, where adoption of this technology outside the US has continued to grow over the last decade.

Clearly, there is a difference in approach and scope between the Shahpar and Argonne studies but this is appropriate, given the focus on a local governmental decision making solution vs. a more generalized approach applicable to many environments. Shahpar offers a conclusion that transit agencies use other transit agencies experience or studies, such as this this work, to perform their own local study but additional local and/or more generalized study will be required to draw those conclusions. The Argonne Report found that commercial intracity truck industry is an area for serious consideration to take advantage of the benefits of NG technologies. Further, these benefits and could be realized with the demonstration of a long-term aggressive future market penetration of heavy-duty NG vehicles. The Energy Information Administration projections and GREET life-cycle modeling of U.S. on-road heavy-duty use NG vehicles data suggest that petroleum consumption reductions of approximately 1.2 million barrels of oil per day are possible. In conclusion, the Argonne Report asserts that this shift in United States industry to NG vehicle usage has the potential for an 8% reduction in daily oil consumption. By the nature and scope of the author's conclusions, it is appropriate to assume that differences in the investigation process regarding the diversity of alternate-fuel technologies under consideration and a focus on a local governmental decision making solution vs. a more generalized approach is reasonable.

2.2 Summary

This chapter presented and analysis of the Argonne Report and the Shahpar Thesis. The Argonne Report showed that the commercial intracity truck industry would be an area for serious consideration to take advantage of the benefits of NG technologies; where this could be achieved with the demonstration of a long-term aggressive future market penetration of heavy-duty NG vehicles. The study found that this shift in the United States industry to NG vehicle usage has the potential for an 8% reduction in daily oil consumption. The Shahpar Thesis showed that hybrid diesel-electric buses rate well according to the criteria of energy, environmental impact, industrial relationship, and implementation cost for DART. Further, this study suggest that each transit agency consider its unique situation and infrastructure before determining what alternative-fuel bus technology provides the most benefit and value. Shahpar found that capital cost varies based upon facilities that transit agencies already have in place and the best purchase option may change based upon the scope of the bus procurement; where, LCC is sensitive to the number of buses that will be purchased.

The analysis of these studies found in this chapter showed the similar methodology in these studies for the investigation of alternative-fuel technologies, environmentally friendly and cost beneficial alternatives, and correlation of the use of these AFV (Alternate Fuel Vehicle) technologies and the application to fleet use in order to harness the benefit of use from the scalability potential through fleet volume.

Although both of these studies provided good background information and support for the overarching conceptual assertions under investigation in this dissertation, the integration of expert system technology to enhance the analysis within the work and to inform the understanding of other independent reports and studies highlighted in the Shahpar study, in my opinion, provides tangible benefit to the governmental transit community. This is a clear distinction between the Shahpar and Argonne work. While the Argonne Report also provided benefit in a very general way related to the understanding of market factors, barriers and opportunities related to the NG vehicle technology applications, the Shahpar Thesis provided a unique mechanism to inform and contextualize decision making at a local level, as well as, a pathway to extend this work to other environments, by engaging a community of documented experts to inform the understanding of other independent reports and studies. This is a very useful outcome to extend the knowledge base in this important area.

Chapter 3

ANALYSIS OF THE USDOT FUEL CELL BUS PROGRAM

The analysis of the USDOT Fuel Cell Bus Program: Alameda-Contra Costa Transit District (AC Transit) was used in this dissertation to investigate the importance of fleet testing to inform future recommendations for fleet manager decision making under certain fleet conditions.

3.1 Background on the Alameda-Contra Costa Transit District and Context for the Report (www.actransit.org/about-us/celebrating-ac-transits-50th-anniversary/ - accessed on 4/8/16

Voters created the Alameda-Contra Costa Transit District (AC Transit) in 1956 and subsequently approved a $16,500,000 bond issue in 1959 enabling the District to buy out the failing privately owned Key System Transit Lines. In October 1960, AC Transit's service began. The new District built up the bus fleet with 250 new "transit liner" buses, extended service into new neighborhoods, created an intercity express bus network, and increased Bay Bridge bus service. October 2010 marks the 50th anniversary of AC Transit bus service. In the half century that AC Transit has been in operation, the District has expanded its service area considerably, expanded the types of services it offers, and become a leader in the use of alternative fuels. As at its inception, AC Transit is continually looking forward for better ways to move people.

3.2 USDOT, FTA National Fuel Cell Bus Program: Accelerated Testing Evaluation Report (U.S. Department of Transportation, Federal Transit Administration, 2009)

Since March 20, 2006, the Alameda-Contra Costa Transit District (AC Transit) has operated revenue service buses within the FTA's National Fuel Cell Bus Program (NFCBP). There have been previous evaluation reports from the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) on the AC Transit project. Although the AC Transit buses were operational, these buses were prototype and demonstration vehicles, where the major objective of the testing was to acquire a knowledge base via operational data gathering to inform future design considerations through the identification and resolution of potential in-service anomalies and failures. The evaluation testing was designed to stretch this technology to the operational limit to identify any design issues that could be mitigated in later technology builds.

Generally, this report was well organized. The report is organized in a way that provides context to the overall thought processes of this organization as it attempted to align itself with this national demonstration effort. It reads at a very informative level which is easily comprehendible by a wide audience. Given the public nature of this project, this is considered a clear benefit in providing useful and understandable information for the end users within the public domain.

The operating data for the earlier evaluation of these prototype fuel cell buses suggested that the implementation was success. These vehicles had no safety incidents and public interest and support of the project implementation was generally positive.

One shortcoming of the testing was the level of bus usage and availability. By AC Transit standards, operational utilization was considered low; 58% utilization was achieved where 85% was the projected target. Further, another parameter referred to as Miles-Between-RoadCalls (MBRC) did not reach the expected target and the operational data suggests that a four to seven fold increase would be required to reach the baseline range. As in many initialization studies, much of the early demonstration was about the calibration and derivation of baseline data for the operational ranges of the prototype technology; therefore, it is acceptable that some of the operational targets were not met initially. One of the more important operational targets exceeded expectations. Fuel economy was up significantly for the duration of the test and numbers in excess of 67% were observed.

There were notable issues with the fuel cell power systems and with the traction batteries. These system components were critical to trouble-free operation. System failures of this nature accounted for 82% of the total propulsion-related roadcalls in addition to 73% of the reasons for the buses being “unavailable for service.” The continued (second phase) evaluation testing cited in this report was intended to gather further test data to aid in the mitigation of these issues before future deployment of newer fuel cell bus assets in late 2009 or early 2010, where an operational scenario closer to full transit bus operation was anticipated.

The acceleration testing was intended to be a test bed for the new fuel cell technology; however, there appeared to be fundamental flaws in the system design which seemed to inhibit the test from providing a range of operational data to appropriately inform the decisions-makers with regarding the true operational performance in a revenue service scenario. Perhaps, additional discussion and time spent with the manufacturer before the bus purchase/delivery would have lessened the technical failures during the initial testing phase.

This report was a continuation of the evaluation testing at AC Transit. It should be noted that the funds for the data collection and analysis required by NREL were transitioned from DOE to the Federal Transit Administration (FTA). The duration of the accelerated testing was from November 2007 through October 2008. There were three (3) fuel cell buses under test and the focus of the test encompassed fuel cell bus operations after the last installation of new fuel cell power systems through October 2008 (USDOT, FTA, 2009). Further, the evaluation period for results of the diesel bus operations were from January 2007 through December 2007.

For the prior testing phase and the accelerated testing phase highlighted in this report, it appears that the vehicle test “n=3” was too small to provide significant results, given the early design maturity of the vehicle propulsion and battery technologies. The report cited issues with low MBRC which was 4-7 times less than projected. Clearly the continuation testing that followed at AC Transit, where there were 12 newer and more reliable fuel cell buses under test, was more in line with a performance and evaluation testing paradigm which should yield more useful operational data.

The accelerated test which makes up the bulk of this report was designed to inform the necessary preparation and infrastructure to support the further operation of these three prototype buses as the exercise entered the next phase of enhanced operational testing. This included daily operation, throughout the week, with a 16-19 hour revenue service cycle. Given this increased usage, a redesign of the planning and training processes to support the fuel cell bus sub-fleet was critical. These changes to the testing strategy, or accelerated testing, was designed to provide additional and valuable in-situ operational data to aid the manufacturer's understanding of the required testing and upgrades to the propulsion system to lower the mean-time-between-failure (MTBF) that was observed in the prior testing phase.

The work utilized a passenger survey instrument as a mechanism to gather perception data for the ridership base. Rider estimates for the fuel cell buses was achieve through AC Transit's route ridership estimates and on-board automated passenger counters (APCs); where the total estimate was determined to be nearly 278K passengers from March 20, 2006, through October 31, 2008. Further, more that 50% of the ridership was during the accelerated testing period. These data clearly indicate that during the accelerated testing period the target of increased bus usage was achieved.

When a new technology is considered for public use, it is very important to manage and guide the public relations aspect of the project carefully. The AC Transit hydrogen fuel cell project definitely provided due-diligence to this aspect of the project. It is clear that the management of the public relations aspect of any public works or public demonstration project is a critical part of achieving success. In many ways, it is perhaps as important as testing the technical performance and validity of the project. It will be imperative for the decision making tool to take into account factors which combine performance data with public perception data in order to inform a holistic decision making approach.

The study found that refueling processes and procedures were very important to the safe and consistent operation of bus assets. This is even more critical within the hydrogen fuel cell bus technology space. Two steam methane reformers served as the fuel supply source for the buses. The compressed fuel was transferred into the vehicles at a final pressure of up to 5,000 psi. During the accelerated testing evaluation period, the filling data suggests that the fuel cell bus sub-fleet utilized 8,824 kg of fuel as related to a total of 19,257 kg for the entire revenue service demonstration which represents an overall usage of 33.9 kg/day. Further, the fleet was refueled 422 times during the accelerated testing evaluation period with an average fill amount of 20.9 kg/fill at an average fueling rate of 1.34 kg/min.

AC Transit has had a demonstration partner in the fuel cell testing program since 2003. Golden Gate Transit (GGT). GGT had a different operating environment than AC Transit which provided another dimension to the operational data gathering. GGT had a higher average route operating speed; therefore, fuel economy during operation was significantly higher than data captured at AC Transit. The data suggested that GGT and AC Transit realized fuel efficiency of 8.8 miles per kilogram (Kg) or 10.0 miles per diesel equivalent gallon (DGE) and 6.49 m/Kg or 7.33 m/DGE, respectively. In exchange for participation in the testing, GGT received access to training, infrastructure, information, and lessons learned within the project. In addition, AC transit provided GGT with one of the three fuel cell buses for use during their test cycle; which lasted from February 19 and March 21, 2008; for 24 weekdays.

As of the end of the study, accelerated testing continued at AC Transit. There were three (3) fuel cell buses in operation within the FTA NFCBP. Given the continued operation of the fuel cell bus fleet, AC Transit made an increased investment in infrastructure in the form of personnel, training, and equipment. In addition, CARB (California Air Resources Board) required AC Transit to purchase new and advanced fuel cell bus assets as part of the state's zero-emission bus regulations. The Bay Area was required to have 12 new and advanced fuel cell buses in operation by 2009. AC Transit led a group of transit agencies, the Zero Emission Bay Area (ZEBA) working group, focused on the CARB advanced fuel cell bus demonstration program. The new fuel cell bus assets had improved power systems made by UTC Power which were lighter, more compact, and contained a more advanced and reliable battery/energy storage design. The first buses were secured by AC Transit in 2009-2010.

The testing relied too heavily on in-situ performance data and did not consider other more robust analysis methods in determining benefit to the organization. For example, this testing scenario could have used a portion of a LCA strategy to compare and contrast a PTW (Pump-to-Wheel) estimates with the actual operational performance data as a comparison of theoretical to actual performance as in (McKenzie et al, 2012).

3.3 An Update on the Current State at AC Transit

From March 2006 through mid-2010, AC Transit operated three (3) fuel cell buses, logging over 270,000 miles and carrying over 700,000 passengers, all while achieving significantly greater overall energy efficiency than diesel buses.

AC Transit is operating twelve, third-generation fuel cell buses. The new buses feature a redesigned chassis that is 5,000 pounds lighter than the earlier buses. Each new bus is powered by a 120 kW fuel cell power system, built by UTC Power of Connecticut, and an advanced lithium ion energy storage system by Enerdel of Indiana.

Hydrogen tanks on the roof give the bus a range of 220 to 240 miles, and batteries recharged during braking can provide extra power for acceleration and climbing steep grades (www.actransit.org/environment/the-hyroad/).

Although not contained within this report, the current phase of testing (cited directly above) is much more impressive than the phases presented in this work. There is a much more robust testing strategy and the 12 fuel cell bus sub-fleet has the potential to provide some valuable performance data. The report clearly demonstrates that the "planning and design" of an evaluation test project is, perhaps, as important as the test implementation. This study suggests that AC Transit learned a lot from "doing" as it went through the various phases of testing. Often, an organization does not have the luxury of such a process when testing results need to drive critical decisions of a time sensitive nature.

3.4 Summary

The summary of the USDOT Fuel Cell Bus Program: Alameda-Contra Costa Transit District (AC Transit) in this chapter presented the importance of fleet testing to inform future recommendations for fleet manager decision making under certain fleet conditions.

The chapter highlighted the overall thought processes of this organization as it attempted to align itself with this national demonstration effort. The operating data for the early evaluation of these prototype fuel cell buses showed that the implementation was reasonably successful. As in many initialization studies, much of the early demonstration was about the calibration and derivation of baseline data for the operational ranges of the prototype technology; therefore, it is acceptable that some of the operational targets were not met initially. One of the more important operational targets exceeded expectations. Fuel economy was up significantly for the duration of the test and numbers in excess of 67% were observed.

There were notable issues with the fuel cell power systems and with the traction batteries. These system components were critical to trouble-free operation. The acceleration testing was intended to be a test bed for the new fuel cell technology; however, there appeared to be fundamental flaws in the system design which seemed to inhibit the test from providing a range of operational data to appropriately inform the decisions-makers with regarding the true operational performance in a revenue service scenario.

The accelerated test which made up the bulk of this report was designed to inform the necessary preparation and infrastructure to support the further operation of these three (3) prototype buses as the exercise entered the next phase of enhanced operational testing. It was shown that the vehicle test "n=3" was too small to provide significant results, given the early design maturity of the vehicle propulsion and battery technologies.

This included daily operation, throughout the week, with a 16-19 hour revenue service cycle. Given this increased usage, a redesign of the planning and training processes to support the fuel cell bus sub-fleet was critical. These changes to the testing strategy, or accelerated testing, was designed to provide additional and valuable in-situ operational data to aid the manufacturer's understanding of the required testing and upgrades to the propulsion system to lower the mean-time-between-failure (MTBF) that was observed in the prior testing phase.

The work utilized a passenger survey instrument as a mechanism to gather perception data for the ridership base. These data indicate that during the accelerated testing period the target of increased bus usage was achieved.

The report highlighted the importance of managing project public relations when a new technology is considered for public use. In many ways, it is perhaps as important as testing the technical performance and validity of the project. It will be imperative for the decision making tool to take into account factors which combine performance data with public perception data in order to inform a holistic decision making approach.

This chapter also highlighted a the continuation of the evaluation testing at AC Transit; where, there were 12 newer and more reliable fuel cell buses under test. This was shown to be a more desirable performance and evaluation testing paradigm than the original three (3) fuel cell bus accelerated test.

The testing relied too heavily on in-situ performance data and did not consider other more robust analysis methods in determining benefit to the organization. For example, this testing scenario could have used a portion of a LCA strategy to compare and contrast a PTW (Pump-to-Wheel) estimates with the actual operational performance data as a comparison of theoretical to actual performance.

Chapter 4

DECISION MAKING MODEL TOOLS, ARTIFICIAL INTELLIGENCE AND KNOWLEDGE-BASED EXPERT SYSTEMS

Over the past two decades the use of decision making tools have been prevalent in engineering disciplines. This chapter will provide a summary of decision making tools which focus on the concept of Life Cycle Assessment which involves a holistic view of a particular technology or process under investigation. This chapter will also provide a broad overview of the field of artificial intelligence and the sub-field of knowledge-based expert systems. The use of these tools and technologies has a wide range of applications. In transportation engineering, these tools have be use traditionally been used widely in pavement engineering, traffic engineering, and structural engineering. These technologies will be useful in providing background for the development of the prototype decision making system described in this dissertation.

4.1 Decision Making Tools: A Historical Perspective

From the very origins of mankind and the harnessing of natural resources for the conversion for energy, there has been an interest in understanding the efficiency of energy fuels and the benefit that they could potential provide. Whether in the earliest process of igniting wood fiber to create heat, capturing the powerful forces in the natural movement of water or wind to create work, or releasing the potential energy in fossil fuels through an internal combustion process; man has had the desire to better understand how to maximize the benefit of these processes for himself and his "society." It is clear that the energy efficiency of technologies as it relates to service has been of increasing interest to mankind. It is stated by, (Horne et al, 2009), - Perennial questions arise from Newton's First Law of Thermodynamics – if energy is never lost, in what proportions does it dissipate through various processes? What is the energy benefit and loss in various processes? Also, specifically, for energy generation (i.e. 'conversion'), how much input is necessary to produce a given energy service?

From a power generation perspective, the new technologies of a post-World War 2 era created innovative and exciting possibilities within nuclear, modern wind, geothermal and other alternative energy platforms that literally stretched the boundaries and conventional wisdom around the question of energy balance for the remainder of the twentieth century. This is perhaps where the formal development of contemporary Decision making tools began with the application of sophisticated empirical analysis through early system-level assessment. During this time, the analysis of energy systems became much more complex as the scientific community attempted to understand the on-site unit energy production. Over time, the interest expanded to understanding the holistic process level implications of a given enabling technology. For example, the question of whether a given nuclear generation technology produced more energy than it consumed led researchers to look beyond the generation facilities themselves to 'yellow cake' production and uranium mining, long-term waste management, and even to the impacts on transport (of personnel, materials and equipment) and associated research, development, marketing and management services (Horne et al, 2009). This is the informal beginning of what later became known as Life Cycle Analysis where an approach is taken to assess the production of energy services through a strategic systems level process to identify energy inputs.

The 1960s brought about the development of the first Resource Environmental Profile Analysis (REPAs) which where the precursor to the contemporary Life Cycle Assessment (LCA) processes. One of the first companies to broadly apply some of the principles of LCA was Coca Cola Amatil. A group of scientists, who later began the consulting firm – Franklin Associates, was hired by Coca Cola to study the use of different product packaging materials and their impact on resource utilization and the environment. The gas crisis of the early 1970s put the analysis focus squarely back on the energy sector. By the 1980s; however, the life cycle level investigation was more commonly applied across many market segments from automotive, large appliances and housing. At this time, these types of studies where referred to by interchangeable names, i.e. – eco-balance, cradle-to-grave analysis and life-cycle analysis; however, in 1990, there was agreement that the nomenclature, Life-cycle Assessment, best captured the essence of this activity. This agreement was solidified at a conference held in Vermont by the Society of Environmental Toxicology and Chemistry (SETAC). It was not long after this when SETAC began to develop "best-practice" guides on LCA to inform the industry with techniques to simplify the LCA approach and new methods to handle and quantify data. LCA was then applied to public policy, building and construction, as well as, inter-organization management structures. In early 2000, SETAC and the United Nations Environmental Program (UNEP) formed the UNEP/SETAC Life Cycle Initiative to promote the further development and adoption of LCA leveraging the early use of these practices in Europe, the US and Japan. Fig 4.1 highlights the timeline for the early development of LCA in various market segments.

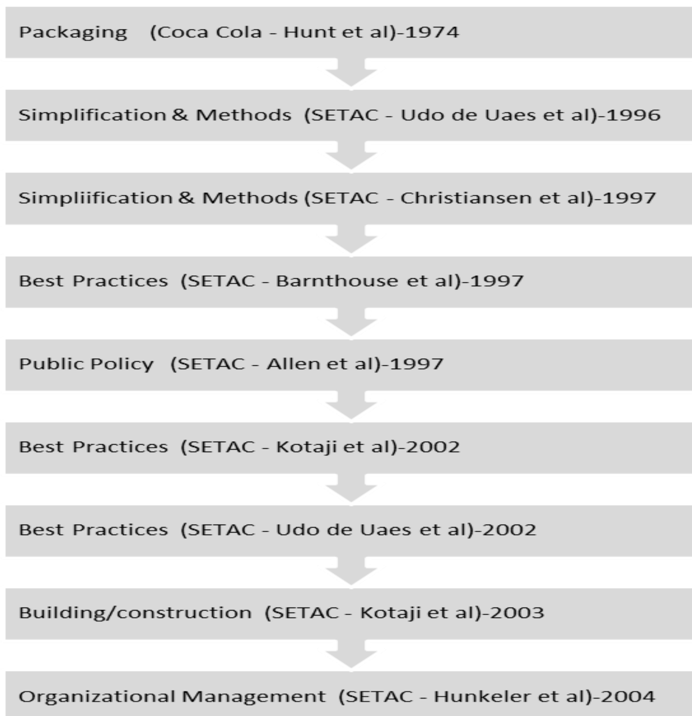


Figure 4.1: Timeline for development of LCA (Horne et al, 2009)

4.2 The Future of Decision Making Tools and LCA

Based upon the findings of this work, I can postulate on where I believe the next generation of advancements will be with these LCA tools. I believe that the next generation of advancements in decision making tools will be in the area of the application of methods to quantify and manage uncertainty. In particular, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes. The fleet decision making process in most governmental agencies is a very complex and interdependent activity. There are always competing forces and agendas within the view of the decision maker. Rarely is the decision maker a single person although, within the transit environment, there is often one person charged with the responsibility of fleet management.

The study (Patil et al, 2010), which is covered in more detail in chapter 5.1, described a scenario/system where actors (decision makers), technologies and rules inform one another. The study defined this as a socio-technical system where the interactions can be analyzed and, subsequently, estimated. The rules (policies) can be greatly influenced by public sentiment and/or perception in addition to technology ... and vice versa. Clearly, there is much work to do in this area. As industry decision experts begin to increasingly understand the relationship between their role and the impact on policy and technological development, this will help to quantify and contextualize the uncertainty associated with this complex systems. As a result, the analysis community will be able to use these inputs to inform their models to aid and inform overall decision making.

4.3 Artificial Intelligence

Artificial Intelligence (AI) is a field of study which defines the characteristic of a computer or computer algorithm which exhibits intelligent behavior. These behaviors are deemed “intelligent” compared with human thought behaviors; within certain parameters and acceptable limitations. The next logical questions to consider might be the definition of human intelligence. Is it the ability to simply acquire knowledge or to reason? Perhaps it is the ability to develop, shape and communicate ideas. It may very well be some combination of all of these attributes of human cognition. For many years a functional definition of AI seemed impossible to articulate but over the years, a definition has emerged which seems to be the integration of multiple information processing and information representation attributes. This field of study is very broad with multiple sub-fields that are generally divided by classes of problems or goals that can be applied and associated with the sub-field. Traditionally, AI technologies have developed around certain classes of problems. These problems include learning, natural language processing, perception, knowledge, etc. The overall goal of the field of AI is to allow computers to be more useful in solving some of the most pressing problems of our age. In this sense, there is a broad audience for the benefits that AI can provide across and wide multi-disciplinary spectrum.

4.4 Knowledge-based Expert Systems

For the benefit of this dissertation, this research focuses on the special class of AI called knowledge-based expert systems (KBES). KBES are a class of computer programs that use data (knowledge) to solve a problems. The critical factor in KBES is that they are designed to emulate the behavior and functionality of the human brain. In this way, these types of systems employ experience based processes, which approximate human thought, to solve problems. The experience based processing is derived from experts in a given area of study. KBES platforms are used across a wide range of industries to inform decision making and aid in problem solving. For example, if an airline wanted to help its novice pilots to develop more advance skills in flying a certain type of aircraft, the design and use of a KBES could be used in this process. The basic process for developing the KBES would involve the development of a prototype to explore the basic approach in solving this problem. The prototype is a first attempt at structuring the problem to prove the feasibility of the basic approach. Typically, the prototype KBES is very rough and brief in its implementation; where the results of testing are viewed as very preliminary in nature. The concept is designed, modeled and verified via the prototype testing. The result of this testing is used to inform the further development of a more robust KBES architecture. The knowledge engineer must understand not only the appropriateness of the knowledge but also understand how it can best be processed to solve problems. According to the work of (Faghri, 1989), in order for the KBES to be considered skillful a some task, a KBES must have a knowledge base containing adequate knowledge about the problem domain, as well as, an inference engine containing the knowledge and its effective use. In the novice airline pilot training example above, the overall prototyping process would involve a knowledge engineer interfacing with domain experts (advanced pilots) to extract knowledge (data) to construct the knowledge base and the inference engineering (rules) to design the prototype KBES for the training benefit of the user (novice pilots). To design the KBES the knowledge engineer would use an expert system building tool platform to host the KBES design. The overall KBES building process can be seen in figure 4.2 below.

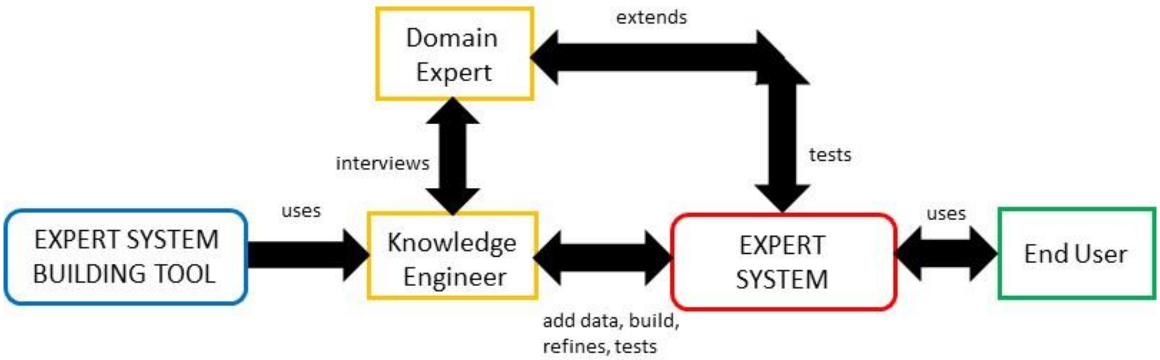


Figure 4.2: KBES building process

Again, this example describes a KBES prototype system which will enable novice pilots to develop more advance skills in flying a certain type of aircraft. The interview of the domain expert(s) provides the data (knowledge) and the rules to put that know to use. The overall process involves the addition of data, building, refining, testing, extending and testing. The prototype development is an iterative process which yields a finished product which moves closer and closer to the desired knowledge based expert system.

4.5 Summary

This chapter provided overview of decision making tools which focus on the concept of Life Cycle Assessment which involves a holistic view of a particular technology or process under investigation. This chapter also provide a broad overview of the field of artificial intelligence (AI) and the AI sub-field of knowledge-based expert systems (KBES). In transportation engineering, these tools have traditionally been used widely in pavement engineering, traffic engineering, and structural engineering. These technologies have proven useful in providing a foundation for the development of the prototype decision making system described in this dissertation.

Chapter 5

UNCERTAINTY IN DECISION MAKING

"There are some things that you know to be true, and others that you know to be false; yet, despite this extensive knowledge that you have, there remain many things whose truth or falsity is not known to you. We say that you are uncertain about them. You are uncertain, to varying degrees, about everything in the future; much of the past is hidden from you; and there is a lot of the present about which you do not have full information. Uncertainty is everywhere and you cannot escape from it."

Dennis Lindley, Understanding Uncertainty (2006)

5.1 Background

Perhaps it is best to begin this discussion with a working definition of "uncertainty" and its relationship to "risk" within the context of a decision making environment. Uncertainty and associated risk are ever present in the decision making processes because, by nature, most decisions will yield a "choice" that will impact the future performance state of a given system; where the parameters which define the system in that future state are unknown. The definitions below vary in use within different communities; however, it is commonly held by many experts in decision theory, statistics and other quantitative fields that uncertainty, risk, and their measurement are generally defined as follows (https://en.wikipedia.org/wiki/Uncertainty):

1. **Uncertainty** - the lack of certainty, a state of having limited knowledge where it is impossible to exactly describe the existing state, a future outcome, or more than one possible outcome

2. **Measurement of Uncertainty -** a set of possible states or outcomes where probabilities are assigned to each possible state or outcome – this also includes the application of a probability density function to continuous variables

3. **Risk -** a state of uncertainty where some possible outcomes have an undesired effect or significant loss

4. **Measurement of Risk** - a set of measured uncertainties where some possible outcomes are losses, and the magnitudes of those losses – this also includes loss functions over continuous variables

5.2 Investment Decision Making for Alternative Fuel Public Transport Buses: The Case of Brisbane Transport - (Patil, et al, 2010)

The investigation of the Investment Decision Making for Alternative Fuel Public Transport Buses: The Case of Brisbane Transport highlighted in the study in Patel, et al, 2010, was used in this dissertation to investigate the importance of considering uncertainty when developing decision making tool for fleet managers. Further, a strategy for handling the uncertainty that exists within in the decision making process for alternative fuel buses was presented and quantified.

This study suggested that alternative bus technology holds great promise for cities, and by extension, municipalities and other governmental transit agencies; which have interest in meeting very rigorous emissions reduction targets. Given the large revenue service potential of alternative fuel buses within the urban space, they are good candidates for emissions reductions when they are employed as part of a comprehensive urban transit planning process. This study found that decision making for the investment in alternative fuel buses is dependent upon future technological development and emissions standards. Given the uncertainty associated with both of these factors, it is difficult to develop decisions making tools without managing this uncertainty. The objective of this study was to develop an analytical framework to provide more insight into the trends in emissions standards and technology development; and eventually translate these insights into a sound investment decision making strategy.

The fleet decision making process in most governmental agencies is a very complex and interdependent activity. There are always competing forces and agendas within the view of the decision maker. Rarely is the decision maker a single person; although, within the transit environment, there is often one person charged with the responsibility of fleet management. The study described a scenario or system where actors (decision makers), technologies and rules inform one another. The study described this as a socio-technical system where the interactions can be analyzed and, subsequently, estimated. The rules (policies) can be greatly influenced by public sentiment and/or perception. Social LCA (SLCA) is a current area of research which offers a different dimension to the life cycle concept associated with the social implications of the technology under investigation. The work of (Roche et al, 2010) provides one approach in this regard by offering an overview of conceptual frameworks and methodologies, where four approaches are considered: general attitudinal surveys, risk perception studies, non-market economic valuation studies, and other approaches such as those based on semiotic theory; which is the study of or theoretic use of signs and symbols as a portion of a communications strategy. The SLCA may be best categorized as an approach that is complementary to environmental LCA.

It is important to understand the relationship between the actors (decision makers), technologies and rules. Figure 5.1 below illustrates this relationship. It is critical to cite the interdependence between the actor, technology and rule factors within this Socio-Technical System. Further, this is a dynamic systems where the interdependency is shaped by the variance in each of these factors over time. The range of actors (decision makers) in this system is very broad. For example, actors could very well be politicians who interact with this system via the legislation of laws and policies that introduce rebates and incentives that could influence technology and rules development as well as other actors.

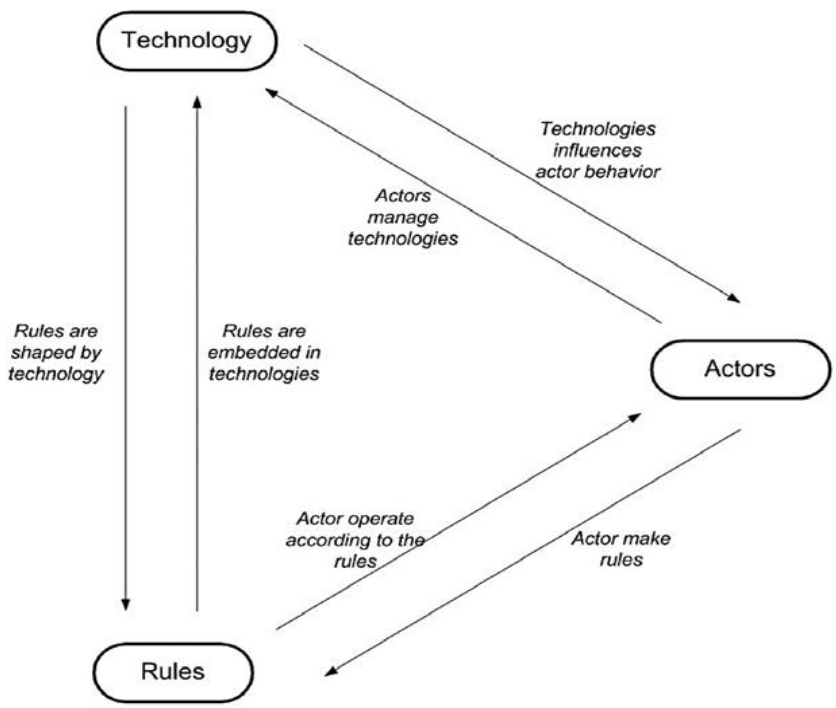


Figure 5.1: Interactions within a socio-technical system (Patil, et al, 2010)

5.3 Value of Applying Decision Making Tools to Guide the Purchase of Vehicles for Transit Fleets

The study (Patil et al, 2010) was successful in highlighting the uncertainty that exists in the decision making process for alternative fuel buses. Most of the uncertainty that is described in the study focused on the technology and emissions requirements. The technology is improving daily, given the interest in alternative fuel applications within the passenger car domain. It is only a matter of time before many of these technologies are mature enough to provide benefit within the fleet bus domain, once the manufacturing and acquisition cost are comparable to clean diesel technology.

It can be argued that all decision making has this same uncertainty given the very complex world in which we live. In fact, this study limited the uncertainty to technology and emissions requirements in order to simplify the solution space. The resulting solution that this study presented for Brisbane Transport is very much aligned with the application of a decisions tool where the uncertainty parameters are controlled by an incremental decision making process. Clearly, the uncertainty is still present but it is managed by the stepwise nature of the asset investment process.

5.4 Summary

This chapter presented an overview of uncertainty in decision making. Working definitions of uncertainty, risk and the measurement of each were provided. Further this chapter provided investigation and analysis of the work of (Patel et al, 2010) where it was shown that decision making for the investment in alternative fuel buses is dependent upon future technological development and emissions standards. Given the uncertainty associated with both of these factors, it is difficult to develop decisions making tools without managing this uncertainty. An analytical framework was presented to provide more insight into the trends in emissions standards and technology development; and eventually translate these insights into a sound investment decision making strategy. Future research should be more comprehensive and could build on the analytical framework discussed in this study to develop a decision making tool for the benefit of public transport authorities (Patil et al, 2010). This study greatly aided my research for this dissertation. The management of uncertainty within the decision making process is very important to inform decision quality; especially as the number of uncertainty variables are allow to grow. An analysis technique that has been in use for some time is the Monte Carlo Simulation. This is a process by which a range of possible outcomes with probabilistic occurrence are simulated to provide a full range of potential outcome states for a physical or conceptual system. The Monte Carlo Simulation process would be good to use in the analysis toolbox to manage uncertainty in decision making. To define uncertainty within the context of decision making, the next two chapters, 6 and 7, will present the uncertainty associated with fuel availability and fuel pricing.

Chapter 6

UNCERTAINTY IN FUEL AVAILABILITY

6.1 Fuel Use and CO_2 Emissions Under Uncertainty From Light-Duty Vehicles in the U.S. to 2050 (Bastani, et al, 2012)

This chapter will present the uncertainty associated with fuel availability by investigating the work of Bastani, et al, 2012; where a stochastic transport emissions policy (STEP) model is presented to quantify the uncertainties in the future fleet fuel use and Green House Gas (GHG) emissions (Bastani, et al, 2012). The study (Bastani et al, 2012) suggested 22% of the CO_2 emissions and over 44% of the oil consumption in the United States is due to on-road transportation. Further, given this very high contribution rate to CO_2 emissions, the application of alternative fuel technologies in this segment were seen as a viable solution. This study focused on the light-duty vehicle (LDV) market within the on-road transportation space. Given the large number of LDV manufacturers and the diversity of features and performance characteristics of these vehicles that could change over time, much uncertainty exists regarding the future impact of current decision making. In other words, decisions made today must be made in order to dictate and guide the development of the LDV market. Therefore, decision makers must take into account the impact of uncertainties on their choices and the risks which coincide with those choices. The study presented a decision making process intended to significantly reduce fuel use and greenhouse gas (GHG) emissions in 2050 within the

LDV market segment. Realistic uncertainty bounds were assigned to the process inputs and an analysis of the uncertainty impact on this pathway was conducted. The study applied a probabilistic fleet model to quantify the uncertainties within two critical areas of importance with regards to the on-road transport GHG emissions and fuel use as follows:

1. Advanced vehicle technology development,
2. Life-cycle emissions of alternative fuels and renewable sources

The analysis in this study was designed to help policy makers develop a better knowledge-base of the impact of their decisions given real-world uncertainties in technology innovation and market changes in the next few decades. This study presented data on the United States where the transport industry produces more GHG emissions than any other sector; where at present 240 million LDVs consume about 530 x 10^9 *l* of gasoline per year. This consumption accounted for 44% of U.S. and 10% of the world's oil use. In 2005 in the U.S., LDVs produced 1260 x 10^6 Mt of CO_2 emissions which account for 22% of the total U.S. GHG emissions, with a growth rate estimated at 1.3%, annually. The uncertainty in the total fuel use and life-cycle GHG emissions from U.S. light-duty vehicles is quantified within the study. The study identified and ranked the major factors which contribute to fuel use and emissions. This process is based on the relative importance of these factors over time. Further, this study presented a fleet development pathway which found an approximate 50% reduction in the fleet GHG emissions and roughly a 40% reduction in fuel use in 2050; however, there were large uncertainties.

In brief, this study used a stochastic transport emissions policy (STEP) model to quantify the uncertainties in the future fleet fuel use and GHG emissions. An overview of STEP is shown in Fig. 6.1. This model utilizes a number of probabilistic inputs that represent the following:

1. Vehicle technology performance
2. Fuel performance and GHG emissions
3. Alternative fuel availability
4. Demand and market deployment of the new technologies and fuel.

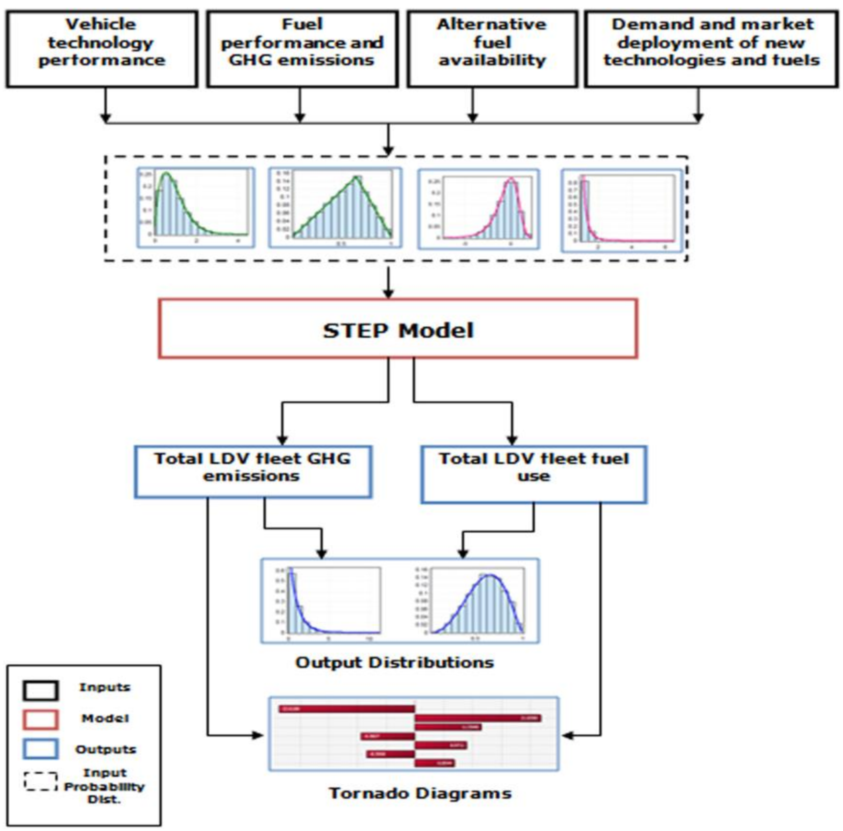


Figure 6.1: STEP model overview (Bastani et al, 2012)

The study found that the expected fuel use is about 500×10^9 and 350×10^9 *l* gasoline equivalent, with a standard deviation of about 40×10^9 and 80×10^9 *l* gasoline equivalent in years 2030 and 2050, respectively. Further, the expected CO_2 emissions are about 1360 and 840 Mt CO_2 equivalent with a spread of about 130 and 260 Mt CO_2 equivalent in 2030 and 2050, respectively. The study concludes that the major contributing factors in determining the future fuel consumption and emissions of these LDV are:

1. Vehicle scrap rate
2. Annual growth of vehicle kilometers travelled in the near term
3. Total vehicle sales
4. Fuel consumption of naturally aspirated engines
5. Percentage of gasoline displaced by cellulosic ethanol

The study found that this type of analysis would better inform policy makers with an understanding of the impact their decisions and proposed policies within the context of the existing technological and market uncertainties.

6.2 Quantification of the Uncertainties in Fuel Availability, Fuel Costs, Development of New Technologies in a Decision Making Model

The study (Bastani et al, 2012) provides an analysis the CO_2 emissions of light-duty vehicles in the U.S. to the year 2050. Inherent in this study is a level of uncertain which is largely due to the time bound of the problem and factors described above such as technology development and life cycle emissions. The duration of time within this study is now until the year 2050 or approximately 40 years.

Given the way the problem is defined within this study, I would suggest that there are many similarities between this study and the research contained in this dissertation.

On the surface, the useful vehicle life defined in the study appears to be of issue. The useful life of the LDV (vehicle scrap rate) at 10 years is much less than that of the transit bus at 20-25 years. Any decision today could have repercussions for the next 25 years or so as the life cycle of a regular bus constitutes 20 years in addition to a lag time of about 4 to 5 years for the process of order and delivery (Patil, et al, 2010). If we look broadly at the range of this study and its 40 year duration it offers possibilities for alignment. Further, there are many correlations between the LDV segment and the transit bus segment. This is especially true in the area of technology innovation and use of alternative fuels, engine design, hybrid systems, etc. In addition, the analysis of life-cycle emissions of alternative fuels and renewable sources would be very consistent with this study.

6.3 Summary

This chapter provided information regarding the uncertainty associated with fuel availability. The work of Batani, et al, 2012, was present; where a stochastic transport emissions policy (STEP) model is presented to quantify the uncertainties in the future fleet fuel use and Green House Gas (GHG) emissions. Further, the uncertainty in the total fuel use and life-cycle GHG emissions from U.S. light-duty vehicles was quantified. It was shown that the identification and ranking of the major factors which contribute to fuel use and emissions could be achieved. This process was based upon the relative importance of these factors over time. Further, this study presented a fleet development pathway which found an approximate 50% reduction in the fleet GHG emissions and roughly a 40% reduction in fuel use in 2050; however, there were large uncertainties remaining in these estimations.

It was shown that his study offers much promise for suggested pathways to quantify the uncertainties in fuel availability, fuel costs, development of new technologies (e.g., batteries for electric vehicles), etc. Given what is presented in this study and other work in this area, it is concluded that any effective decision making tool must have a mechanism to manage uncertainty in a way that mitigates the associated risk in a manner consistent with the cost containment philosophy that is important to the decision maker.

Chapter 7

UNCERTAINTY IN US FUEL PRICING

This chapter will present the uncertainty associated with fuel pricing by presenting information found in various reports and studies on this topic. The concept of uncertainty in fuel pricing is based upon the volatility in the global fuel market due to a wide range of independent factors and variables. Alternative fuel prices fluctuate greatly per gallon relative to conventional fuels. There are many factors that contribute to this pricing variability. Analysis of pricing fluctuations are impacted by many factors, including actual price changes as a result of global supply dynamics, the price sampling methodology by both location and fuel quantity, and seasonal demand. Based upon these factors, there is an inherent uncertainty in pricing predictability of fuel.

7.1 Background

According to the report (USDOE: Clean Cities Alternative Fuel Price Report, January 2015), on an energy-equivalent basis, CNG is about $.19 per GGE (gasoline gallon equivalent) less than gasoline. On a per-gallon basis, E85 is about $.09 less than gasoline, and propane is about $.62 higher than gasoline, but $.14 lower than diesel. B20 prices are higher than regular diesel by about $.12 per gallon, while B99/B100 blends have a cost of about $.96 per gallon more than regular diesel. Prices in this report were collected and reported in the units in which they are typically sold (dollars per gallon or dollars per gasoline gallon equivalent). Because these fuels have differing energy contents per gallon, the price paid per unit of energy content can differ somewhat from the price paid per gallon.

Consistent with this methodology, alternative fuel prices, in terms of price per gallon equivalent, are traditionally higher than their price per gallon because of their lower energy content per gallon. Even given this situation, the appeal and consumer interest in alternative fuels tends to increase when the alternative fuel price is less than the conventional fuel price and as the price differential per gallon increases. This may be counter intuitive since this differential does not typically translate to savings on an energy-equivalent basis.

In this study we will focus on three major areas which have direct implication on the uncertainty in fuel pricing. These areas are as follows:

1. Energy availability in the US fuel market
2. The role of global market volatility in US fuel pricing
3. The future of predicting alternative fuel pricing to inform decision making tools

7.2 Energy Availability and the US Fuel Market

Energy is an important commodity in our global and US economy. All products, goods and services that are produced, sold and/or operated have a quantifiable energy load which must be considered in the broad context of energy Life Cycle Analysis (LCA). Our domestic and global society has become very energy dependent. In this sense, energy is the life blood which fuels our economies and the very progression of our society. This constant need for an ever increasing energy availability has caused most societies to reimage their energy strategies for the future. Here is the U.S., we have long been dependent on foreign petroleum sources to meet our high demand; where the foreign percentage of our petroleum consumption has been as high as 66 percent. Clearly, this level of dependence on foreign energy resources was unsustainable and further caused significant National security exposures for the U.S. This is largely due to the fact that this situation places the future of the U.S. energy security under the control of another global state. It would follow then that foreign energy dependence is not a desirable option for the U.S. in the long-term. As a result, the U.S. is in the process of developing and implementing a comprehensive strategy for energy independence; however, this very complex strategy will be implemented over a long time horizon. The complexity inherent in this strategy is due to the many factors of energy availability which must be addressed from domestic fuel exploration to consumer energy conservation and utilization.

There is a growing body of research and infrastructure investment in the public and private domain which is informing the trend toward U.S. energy independence. Many of these efforts are focused on leveraging renewable, sustainable and alternative fuel resources to lessen the need for foreign petroleum resources. On a large scale, energy possibilities within the advanced nuclear power, wind power, solar power, and biofuels space are beginning to show great promise. Further, there is heightened investigation of and investment in technologies that minimize carbon dioxide emissions and the release gases to the atmosphere.

According to the report (National Academies: What you need to know about energy, 2008); such efforts are especially consequential as worldwide consumption trends put increasing pressure on traditional energy sources. In the United States alone, energy consumption is projected to rise 20% above present levels over the next two decades. Worldwide demand is forecast to nearly double by 2030. Much of that growth will be in developing nations – most notably China and India, which between them contain more than one-third of the planet's people which will create unprecedented competition for limited conventional resources.

Whatever happens, three developments are certain. First, fossil fuels will be a major part of the world's energy portfolio for decades to come because no single technology will provide all of tomorrow's energy and because it takes time and money to change the distribution and consumption patterns of large populations. Second, invention and development of more cost-effective, low-carbon energy sources will become progressively more urgent. And third, bringing those new technologies to market in convenient and affordable forms will pose a challenge even more daunting than the research itself.

7.3 The Role of Global Market Volatility in US Fuel Pricing

It is widely held that crude oil pricing is one of the most critical factors in the global economy. Fluctuation in crude oil pricing can have devastating effects on the general economic, social and financial situation throughout the world. This cause and effect dynamic dates back to the 1970s and 1980s when notable political events in the Middle Eastern region created crude oil supply issues which in turn impacted the global pricing in the crude oil market. Although this effect was initiated decades ago, oil price volatility due to similar events have increased in size, complexity and frequency (Figure 7.1). Oil demand, by its very nature, is somewhat static and correlated strongly with economic growth and to some extent climate policies. It still remains that future oil supply is highly uncertain – in view of sustained political instability in exporting countries and the inherent uncertainty related to fuel exploration activities. These factors and others, create the perfect storm for uncertainty in oil pricing; where drastic fluctuations in the future are fairly commonplace. For example, the use of shale oil fracking at an increased level has led to the destabilization of global fuel prices due to increased supply.

Figure 7.1: Percentage changes of the quarterly price of crude oil (Source: Dow Jones & Co., Thomson Reuters)

Sudden fluctuations in oil prices can be transmitted into the macro-economy in numerous ways from effects in commercial productivity, employment to monetary exchange rates, etc. The extent to which these effects impact a macro-economy is greatly dependent on the core features of that economy; i.e., economies more leveraged in the oil trade are more exposed to price fluctuations on global commodity markets. Further, economies with a high fossil fuel mix in their overall energy footprint and/or energy intensive industrial production, are vulnerable to fluctuations as well.

Although an oil price increase may be perceived positively by oil exporting countries and negatively by importers, a general increase in oil price volatility (which is defined as consecutive positive and negative oil price shocks) increases the perceived price uncertainty for all impacted countries – where their individual trade balance is not a factor. As a consequence, oil price volatility alters planning timing and strategy, promotes delayed infrastructure investments, and may prompt the costly reallocation of resources. Often an importing country must negotiate the prospect of a less than favorable economic outlook as budgeting levers begin to tighten in the face of uncertainty related to import costs and fuel subsidy levels. At the same time, exporters face volatile revenues. This is a more devastating condition in budget challenged developing countries, where the dependence on oil exports is a significant source of public revenue. This price volatility can cause havoc on a country's economy, if left unchecked. Many countries employ a strategy of fuel subsidy to shield industry and the general public from the price volatility of the international marketplace. Unfortunately, these fuel subsidy strategies often introduce significant budgetary risks and environmental costs. In addition, these strategies tend to benefit the richer segments of the population, limit energy efficiency, and consume resources which could be allocated to education, healthcare and other important areas of societal benefit.

It is critical to mention at this point that volatility and uncertainty not interchangeable. Uncertainty can and does exists even in the absence of volatility. Situations have been observed where prices remain effectively stable over an extended timeframe and an unexpected event disrupts the social and/or political landscape resulting in a significant upward or downward price change (i.e., natural disaster or weather event). When prices are stable; however, there is a tendency to discount this permanent underlying uncertainty when considering economic decision making. The harsh reality remains that governments are more likely to consider future price uncertainty when making investment decisions, within an environment of volatile fuel prices. In the final analysis, oil price volatility often results in perceived economic uncertainty, whereas the absence of volatility often promotes an artificial sense of stability. In this sense, it is prudent for policy makers to adopt a comprehensive risk management philosophy. Such a comprehensive approach suggests the need to accounting for related risks like the price volatility of other key commodities.

One method of mitigating an entity's fundamental exposure to price volatility is the deployment of various policy instruments. Often, these strategies focused on reengineering the core economic structure to limit the level of dependency on international commodity markets. These instruments include, but are not limited to, limiting the percentage of fossil fuels within the national energy portfolio, promoting energy efficiency, and developing infrastructural and technological alternatives to limit the fossil fuel load. In addition to these strategies which tend to be long term solutions, it is also important to consider shorter horizon risk management strategies focused on the development of physical reserves, strategic purchasing contracts and financial instruments.

7.4 The Future of Prediction of Fuel Pricing to Inform Decision Making Tools

Based on the research contained in this dissertation, I predict that the next generation of advancements will be with these alternative fuel LCA tools. I believe that the next generation of advancements in decision making tools will be in the area of the application of methods to quantify and manage uncertainty. In particular, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes. The fleet decision making process in most governmental agencies is a very complex and interdependent activity. There are often competing forces and agendas within the decision space of the decision maker. Rarely is the decision maker a single person although, within the transit environment, there is often one person charged with the responsibility of fleet management. The study (Patil et al, 2010) described a scenario/system where actors (decision makers), technologies and rules inform one another. The study defined this as a socio-technical system where the interactions can be analyzed and, subsequently, estimated. The rules (policies) can be greatly influenced by public sentiment and/or perception in addition to technology ... and vice versa. Clearly, there is much work to do in this area. As industry decision experts begin to increasingly understand the relationship between their role and the impact on policy and technological development, this will help to quantify and contextualize the uncertainty associated with these complex systems; in this case, the important area of uncertainty in fuel pricing. As a result, the analysis community will be able to use these inputs to inform their models to aid and inform the overall decision making process.

7.5 Summary

This chapter presented information to highlight the concept of the uncertainty associated with fuel pricing. It was shown that this is an inherent uncertainty in the pricing predictability of fuel. In this chapter, three major focus areas were presented which have direct implication on the uncertainty in fuel pricing; 1) energy availability in the US fuel market; 2) the role of global market volatility in US fuel pricing and: 3) the future of predicting alternative fuel pricing to inform decision making tools.

Regarding energy availability in the US fuel market, energy consumption is projected to rise 20% above present levels over the next two decades; where, worldwide demand is forecast to nearly double by 2030.

Regarding the role of global market volatility in US fuel pricing, information was presented to distinguish to concepts of volatility and uncertainty. It was shown that uncertainty exists even in the absence of volatility. When prices are stable; however, there is a tendency to discount this permanent underlying uncertainty when considering economic decision making.

Regarding the future of predicting alternative fuel pricing to inform decision making tools, a prediction was presented on the next generation of advancements alternative fuel LCA tools in the area of the application of methods to quantify and manage uncertainty. Specifically, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes.

Chapter 8

CRADLE TO GRAVE COMPREHENSIVE ANALYSIS FOR ALTERNATIVE FUELS

8.1 Introduction

The concept of “From Cradle to Grave” as related to a comprehensive cost-benefit analysis of alternate fuels is a critical component of understanding the potential benefit of a given technology. This is best captured within a discussion of the mature theory of Life Cycle Assessment (LCA). The concept of LCA involves the large range of environmental factors which are associated with products and services in order to support process development, influence policy and promote informed decision making. Life cycle refers to the concept wherein an open and broad-based assessment demands the investigation of materials extraction, manufacturing, distribution, application and use, and subsequent disposal processes that are necessary as a result of the creation and/or existence of a given product and/or technology.

Generally, the two primary categories of a LCA are the attributional LCA (ALCA) and the Consequential LCA (CLCA). The ALCA defines the factors associated with the production and use phase for a given product, service or process. There is a time duration associated with the ALCA, which is often constrained to the recent past. The CLCA define the factors associated with the environmental results and outcomes of some policy change or decision making process in a system or technology under investigation.

The time duration associated with the CLCA is focus on the future, where economic impacts resulting from the decision making process are analyzed. Social LCA (SLCA) is a new area of research which offers a different dimension to the life cycle concept associated with the social implications of the technology under investigation. The work of (Roche et al, 2010) provides one approach in this regard by offering an overview of conceptual frameworks and methodologies, where four approaches are considered: general attitudinal surveys, risk perception studies, non-market economic valuation studies, and other approaches such as those based on semiotic theory. The SLCA may be best categorized as an approach that is complementary to environmental LCA.

8.2 Cradle to Grave Comprehensive Cost-Benefit Analysis of Alternative Fuels

When one considers a cradle to grave approach to cost-benefit analysis for alternative fuels, what sources of emissions should be considered? Should more than tailpipe emissions be considered in this energy assessment? Is there potential environmental damage caused by emissions from power stations? There is a class of analysis methodologies that are based upon well-to-wheel (WTW), cradle-to-grave (CTG) or life cycle assessments (LCA), which consider the various phases in the life and use of a vehicle, from its manufacture and the production of its fuel, as well as, the use of the vehicle and the construction/maintenance of the required vehicle support infrastructure, and recycling processes. Figure 8.1 below illustrates this approach.

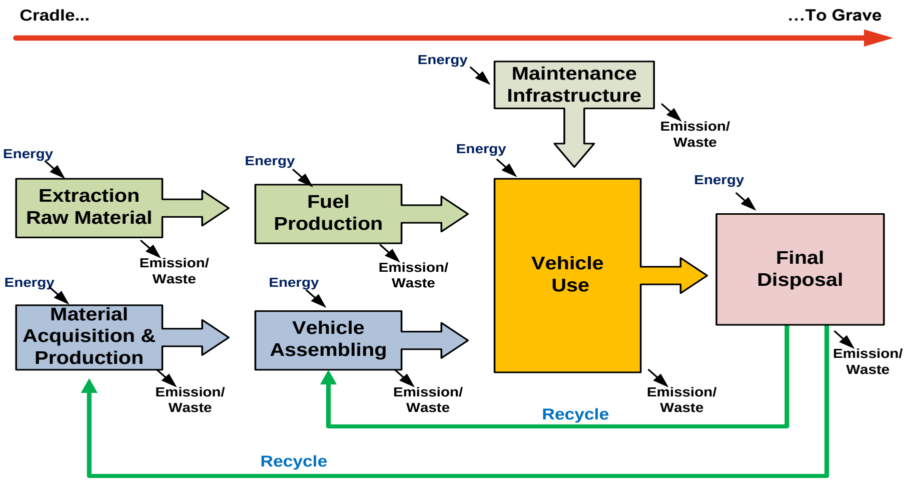


Figure 8.1: Cradle to grave overview (adapted from Van Mierlo et al, 2003)

The emissions from the extraction and transportation of raw materials as well as those related to the refining and distribution of the fuels are considered "indirect" emissions. A well-to-tank analysis of this type is important to compare and contrast different fuels, since there can be significant differences in the emissions related to the production process. For this study we will look at two examples of vehicle fuels: petroleum and electric. Clearly, there are major differences in the indirect emissions related to the production processes of conventional vehicle fuels like petroleum and those of electricity. For simplicity we will only examine the emissions analysis understanding that there is a corresponding cost analysis which can be examined as well.

The production of petroleum is a complex process which starts with the extraction of the raw material which is crude oil. There are various phases within the extraction process where each has a related emissions output. The typical extraction processes are gas flaring, venting and the use of gas turbines. In the transportation phase in petroleum production there are emissions associated with the use of energy for transport vehicles and losses within transport. In the processing phase (refining), there are emissions at the refinery level, which can vary depending on the type of refinery. Lastly, the distribution of petroleum fuel can have emissions impact due to volatile organic compound (VOC) evaporation at various points in the process.

The general indirect emissions associated with electric power generation are related to the type of power station used to generate the electricity. There are various forms of electric power generation, i.e. nuclear, coal, wind, hydro, etc. Even in the case of wind and hydro, which on the surface seem to have no environmental load, there is an environment cost associated with the construction and maintenance of the wind and hydro generation systems, as well as, the manufacture and transport of parts and services for these facilities.

If we look at the case of electricity used as a vehicle fuel, it is very difficult to attribute the electricity used, by a particular vehicle or fleet, to a specific power generation source. However, various methodologies can be employed and assumptions applied in order to estimate the source of the power and associated emissions. For example, if we assume a service use cycle for an electric vehicle to be during the day then it may be also reasonable to assume the charging cycle to be at night. The power generation sources of electricity production are very different during the day than at night when the generation typically switches from a conventional power station to the "base" power station. It follows then that this assumption of night-time vehicle charging would allow us to focus our emissions analysis on the base power station; which is generally more efficient with lower relative emissions than the power station. At first glance it may appear that the indirect emissions associated with electricity production is very high, but this is counter-balanced by the fact that there are no direct tailpipe emissions as is the case for the other types of fuel used in vehicle. It is important to note that indirect emissions are not typically produced at the place of vehicle operation other than the transport phase for certain fuels. In the case of petroleum and electricity, refinery plants and electricity production plants are often constructed in less densely populated areas, where the impact of their environmental loading on human health is lower than those of direct tailpipe emissions because of the dispersion factor of these indirect emissions.

8.3 The Future of Decision Making Tools

Based upon the findings of this research, it can be postulated that the next generation of advancements will be with these LCA tools. Specifically, the next generation of advancements in decision making tools will be in the area of the application of methods to qualify and manage uncertainty. In particular, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes. The fleet decision making process in most governmental agencies is a very complex and interdependent activity. There are always competing forces and agendas within the view of the decision maker. Rarely is the decision maker a single person although, within the transit environment, there is often one person charged with the responsibility of fleet management.

The study (Patil et al, 2010) described a scenario/system where actors (decision makers), technologies and rules inform one another. The study defined this as a socio-technical system where the interactions can be analyzed and, subsequently, estimated. The rules (policies) can be greatly influenced by public sentiment and/or perception in addition to technology ... and vice versa. Clearly, there is much work to do in this area. As industry decision experts begin to increasingly understand the relationship between their role and the impact on policy and technological development, this will help to quantify and contextualize the uncertainty associated with this complex systems. As a result, the analysis community will be able to use these inputs to inform their models to aid and inform overall decision making.

8.4 Dominant Alternative-Fuel Buses in Practice

Since the Energy Policy Act of 1992, transit agencies have integrated alternative fuel bus technologies within their bus operations. The Energy Policy act ultimately listed eight fuels designated as alternatives: ethanol, methanol, Liquid Petroleum Gas (LPG), pure electric, hydrogen (fuel cell), Compressed Natural Gas (CNG), biodiesel, and hybrid. Although the Energy Policy cited all eight of these technologies as alternatives, the current APTA's transit bus database suggests that all of these alternative fuel technologies are not viable alternatives for conventional diesel when applied to bus transit.

8.5 Alternate Fuel Bus Asset Use in US

As of 2013, the overall US bus fleet includes 40.4% vehicles that are powered by alternate fuel technologies. The proportion of alternate fuel vehicles has been increasing rapidly in the last few decades – where, only 13.3% and 2% of the US transit bus fleet were powered by alternative fuel technology in 2004 and 1992, respectively. Natural gas vehicles, hybrids, and biodiesel are the most commonly use alternate fuel technologies for transit buses. The US Bus Fleet infrastructure is comprised of (20%) Natural gas, (13.2%) hybrids and (7%) Biodiesel vehicles. Over sixty-one APTA member agencies have hybrid buses in their fleets, and hybrids make up 11% of the vehicles on order at transit agencies. At that time, the New York MTA was by far the largest user of hybrid buses, with a fleet of over 1600 hybrid vehicles. Washington Metrobus and King County DOT both have substantial hybrid fleets with over 600 buses. Seventeen U.S. bus agencies (13% of responding agencies) have 100% alternate fuel fleets.

8.6 Summary

This chapter provide an investigation on the concept of “From Cradle to Grave” as related to a comprehensive cost-benefit analysis of alternate fuels as a critical component of understanding the potential benefit of a given technology.

The cradle to grave approach to cost-benefit analysis for alternative fuels must define the sources of emissions to be considered. There is a class of analysis methodologies that are based upon life cycle assessments (LCA), was presented; where, consideration was given to the various phases in the life and use of a vehicle.

This chapter further presented the concept of the next generation of advancements in LCA tools; where, these advancements in decision making tools were shown to be the area of the application of methods to qualify and manage uncertainty.

Chapter 9

IMPROVEMENTS IN METHODS OF ANALYSIS TO ENABLE BETTER DESIGN AND DECISION MAKING IN FLEET USE OF ALTERNATIVE FUEL TECHNOLOGIES

9.1 Introduction

Given the economic, energy and environmental landscape of the 21st century and beyond, many municipal transit agencies must utilize informed decision making to project the scope and characteristics of future fleet asset acquisition.

In the studies in (McKenzie et al, 2012) and (Haller et al, 2007), findings were presented on different approaches to Life Cycle Assessment (LCA) to represent the research to date within this area. This research will improve upon this work to enable better policy design and decision making by addressing the "uncertainty" within the decision making process for fleet managers, as represented, generally, by (McKenzie et al, 2012) and (Haller et al, 2007). The proposed improvement that I anticipate in the policy arena depends upon slight improvements in the capabilities of program managers and policy staffs to translate my research into better policy and program practice. These improvements are anticipated largely in the area of decision making expert understanding of the uncertainty in the policy development arena and its impact on technology innovation.

9.2 Environmental Life-Cycle Assessment of Transit Buses with Alternative Fuel Technology

The work of **(**McKenzie and Durango-Cohen, 2012), focused on the environmental life-cycle assessment of transit buses with alternative fuel technology. Alternate fuels can address environmental concerns because, in general, tailpipe emissions with these fuels are less than standard diesel fuel. The study provided a life-cycle assessment (LCA) to compare ultra-low sulfur diesel to hybrid diesel-electric, compressed natural gas, and hydrogen fuel cell. This was accomplished through the use of a hybrid input-output (IO) model. The study investigated the life cycle of alternative fuel vehicles (AFV) by estimating the cost of emissions reductions and examining the results sensitivity to variation in fuel prices, passenger demand, and technology characteristics which influence performance and emissions. The study found that alternate fuel buses significantly reduce the cost of operation and tailpipe emissions while they increase life-cycle cost. The infrastructure costs must be taken into account when estimating the total life-cycle cost to deploy and operate these vehicles. Further, the study found that efficient bus choice is sensitive to Passenger demand, but only moderately sensitive to technological characteristics, and that the relative efficiency of compressed natural gas buses is more sensitive to changes in fuel prices than that of the other bus types.

The work of (Haller et al, 2007) focused on the Economic costs and environmental impacts of alternative fuel vehicle fleets in local government. High crude oil prices and increasing public awareness of the environmental impacts of carbon based vehicle emissions have heightened interest in the adoption and use of alternative fuel vehicles (AFV) as shown in Energy Information Administration, 2006b. Policy makers view alternative fuel vehicles as good candidates for fleet applications. At the time of the study, implementation issues associated with alternative fuel vehicle were not well understood even though they are an integral part of understanding the environmental benefits and economic impacts involved in fleet enhancement or conversion.

The study investigated the mid-cycle conversion of a 180-plus vehicle fleet to alternative fuel technology. The study looked at year 5 of a 10-year conversion plan. It should be noted that this conversion was voluntary by a public organization absent any external mandate. The study used multi-year micro data on the following:

1. Fuel usage
2. Operational and capital expenditures
3. Mileage and emissions

Further, the study examined:

1. Conversion costs
2. Infrastructure investments required
3. Extent of user adoption
4. Emissions reductions achieved

The study results were discussed in terms of their impact for managerial practice in local government fleet agencies and for future research.

9.3 Methodology for a LCA Framework

The study (McKenzie et al 2012) presented a methodological LCA framework where two parameters; cost and Green House Gas (GHG) emissions, were captured for the manufacturing and operating processes of the four categories of alternative fuel buses under investigation.

The data for the study was gathered from a series of NREL demonstration studies at New York City Transit, Washington Metro Transit Agency, Alameda-Contra Costa Transit, Sunline Transit Agency and Connecticut Transit.

In these demonstration studies, each transit agency purchased, operated, and conducted performance evaluation of the alternative fuel buses under normal transit operation routes from 2003 to 2009. These data included operational, performance, and maintenance statistics. Further, a detailed cost breakdown for each vehicle was available. Additional data from a ‘‘well-to-wheels’’ study on transit buses were used to calculate emissions from bus operations (Pont, 2007).

A discount rate of 6% is used for both costs and emissions. In determining a reporting metric for cost and GNG emissions, the study found that both cost and GNG emissions should be discounted by 6%. The study presented that this was appropriate to offset the "uncertainty" associated with the use and adoption of new alternative fuel technologies and offered a more balanced comparison of these technologies to conventional diesel technology; where the discount effectively weighted the short term impact of CO_2 equivalent units (CO_2e) more heavily than the long term impact. The study assessed GHG emissions based upon bus manufacturing and operating phases and used a hybrid IO model to assess the manufacturing phase and the construction of support infrastructure for alternative fuel buses, i.e., depots and fueling stations for CNG (Compressed Natural Gas) and HFC (Hybrid Fuel Cell) buses. This IO approach to environmental LCA included specification of the direct requirements, such as, billing of materials for a product in terms of “demand” for economic sectors, e.g., transportation, construction, financial services, etc. This demand is normally expressed in monetary value (US dollars); therefore, this model was used to compute the level of economic activity and environmental repercussions such as GHG emissions; associated with satisfying the given demand for the product. Since all sectors represented in the economy are linked, the study found that there is no effective boundary on the scope of the analysis.

The basic structure of the LCA methodology in this study was derived from the work of (Maclean and Lave, 2003). In this work, there was a comprehensive study of LCAs for fuel and propulsion systems. In (Maclean et al, 2003), there was a focus on processes that represent supply-chain activities such as raw materials extraction, fuel pathway and energy generation characteristic for each type of vehicle. By contrast, the (Maclean et al, 2003) study excluded end-of-life phase processes. The rationale presented for excluding these processes from the LCA was the initial analysis where it was determined that the end-of-life phase had a minimal effect comparatively on the analysis of the fuel cell buses, where the most significant impact was seen in the disposal processes of the lead acid batteries for the hybrid buses.

In order to better ensure that the GNG emissions estimates use in the (McKenzie et al, 2012) study was within range, the study used the data of five (5) other independent studies as a comparison mechanism. When a data range was provided in a particular comparison study, a low and high value was used, corresponding to a worst and best case scenario, respectively.

The results of the LCA were presented with units of cost in ($) where Cost = average fuel economy (miles/gal) x distance travelled (miles) x 2008 average fuel price ($/gal). It was presented that given the 15 year planning duration, with the 6% discount applied, emissions impact from the operation phase clearly outpaced those from the manufacturing phase; contributing from 74 – 85 percent of total emissions. However, the operations phase accounted for only 35 – 58 percent of the overall cost.

The study concluded with a sensitivity analysis of the LCA output. By definition, a sensitivity analysis in LCA is intended to study how the "uncertainty" in the output of a LCA can be correlated to various sources of uncertainty in the inputs of the LCA. In this way, uncertainty analysis, which has a greater focus on uncertainty quantification and propagation of uncertainty, should be considered in tandem.

The (Haller et al, 2007) study presented a three part assessment including cost effectiveness analysis, implementation evaluation, and environmental outcome analysis. The data in this study was gathered from the Forest Preserve District of DuPage County, IL (Forest Preserve) for a full range of vehicles in its fleet; from passenger cars to heavy duty vehicles. Forest Preserve provided almost five years of micro-data with granularity down to the vehicle level. Forest Preserve provided capital and infrastructure data – i.e., vehicle purchase costs, fuel station costs, and education/ training – some of these data were only available in paper form, including photocopies of original purchase receipts. In addition, transaction level detailed data was made available which included the following:

1. Cost and quantity of fuel used per vehicle
2. Parts costs
3. Labor hours for repair and maintenance.

This level of detail was possible because most fleet services organizations, like the Forest Preserve, maintain a substantial transaction-based fleet maintenance database. Forest Preserve provided other detailed data such as: financial data on vehicle purchases (both vehicles converted before purchase and those converted after), receipts for other items such as consultants, architects and training that were not included in the database, and EPA rebate receipts provided by the Forest Preserve to the EPA for vehicles where no conversion data was available. Both the cost effectiveness and implementation evaluation assessments utilized data from manual and automated inputs of fuel and transaction data, depending upon where the fuel was purchased. For the implementation evaluation analysis, vehicle miles traveled (VMT) was provided through a calculation comparing the odometer reading within the study duration. The VMT calculation for bio-fuel vehicles was handled through a process to proportion primary fuel to secondary fuel via standard miles per gallon (MPG) for single fuel vehicles of same fuel type and weight class times gallons consumed. Any remaining VMT was allocated to the alternative fuel. Finally, the diesel supply was converted to B-20 biodiesel fuel on April 15, 2002 including some non-sanctioned outside purchase of regular diesel fuel occurring after that date, but the effect was expected to be minimal.

The cost effectiveness analysis captured the funds expended to implement the alternative fuel technology. The study utilized a standard methodology (Kee, 2004) and (Rossi et al, 2004) for the cost effectiveness analysis of the assessment. The study suggested that there is a correlation between cost effectiveness and program effectiveness and as a result the study selected “dollar per mile” as the appropriate cost effectiveness measure to compare across multiple alternative fuels. All dollars were converted to 2001 level dollars.

The second assessment in the study analyzed the fleet use of alternative fuels. Again, a standard implementation evaluation model and methodology was used to assess the number of AFV purchased by Forest Preserve and the fleet drive fuel use characteristics. This analysis addressed three critical components:

1. Program coverage
2. Whether the program is being implemented as planned and is producing the expected outputs
3. Differences in fuel use by fuel type for the fleet as a whole.

These items were intended to provide an analysis of overall program acceptance by the identification of any implementation biases as indicated by differences in participation.

The last assessment in this study sought to quantify the energy and air quality gains seen at the midpoint of the Forest Preserve conversion process. Two different methods were used to calculate emissions reductions within the Forest Preserve fleet. Passenger and light truck emissions were calculated via the volatile organic compound

(VOC) reductions estimates, within the GREET (Greenhouse Gas, Regulated Emissions, and Energy use in Transportation) Model. The GREET Model calculated energy use and emissions for AFV and factors for well-to-pump (includes energy and emissions relevant to feedstock and fuel related stages) and pump-to-wheel cycles; where the overall well-to-wheels assessment includes vehicle refueling and operations. The formula for energy use includes energy use, fossil fuel energy use, and petroleum use, while the formula for emissions includes carbon dioxide, methane, nitrous oxides and five ‘‘criteria’’ pollutants (Brinkman et al, 2005).

The study derived an initial cost estimate and conversion schedule for the 10-year Forest Preserve implementation plan for a baseline comparison to the effectiveness assessment and implementation evaluation. The idea was to provide a baseline case to contextualize the analysis results. However, the study highlighted that the substantive meaning of the baseline outside the confines of the study was limited because the calculations for the baseline relied on non-transparent estimations made by a Forest Preserve private sector consultant prior to the start of the conversion program. The baseline case presented in this study showed an anticipated net savings over ten years as a result of the AFV conversion effort. This initial conversion plan assumed that the number of vehicles converted to alternative fuel use would be equally distributed throughout the ten-year period (10% of units per year) and that each unit would use 100% alternative fuel upon conversion (Haller et al, 2007). The diversity of vehicles under investigation was expected to be approximately 60% LPG vehicles, 30% NG vehicles, and 10%

vehicles utilizing E-85. Since this is a fifth year mid-point study, all comparisons were made against values that are 50% of the project baseline.

The results of the study suggested that Forest Preserve experienced a complex array of decision criteria, variability in the external environment, and slower than desired rate of conversion. The study found that Forest Preserve was able to convert 50% of its fleet to bio-fuel technologies but was unable to realize anticipated cost savings and emissions reductions. The primary contributor to the shortfall in expected savings was not being awarded of some of the expected grant programs to support the installation of fast fuel stations and other fueling infrastructure.

9.4 Improvements in Methods of Analysis to Enable Better Design and Decision Making

The (McKenzie et al, 2012) study showed that alternate fuels can address environmental concerns because, in general, tailpipe emissions with these fuels are less than standard diesel fuel. The study provided a life-cycle assessment (LCA) to compare ultra-low sulfur diesel to hybrid diesel-electric, compressed natural gas, and hydrogen fuel cell. The hybrid input-output (IO) model presented was a good methodology to support this study. The study investigated the life cycle of alternative fuel vehicles (AFV) by estimating the cost of emissions reductions and examining the results sensitivity to variation in fuel prices, passenger demand, and technology characteristics which influence performance and emissions. This sensitivity analysis is critical factor in understanding the decision making process for fleet management as related to a methodology to mitigate the uncertainty.

It is critically important to consider the data source used in the (McKenzie et al, 2012) study. In this study, five NREL demonstration studies were used. In these demonstration studies, each transit agency purchased, operated, and conducted performance evaluation of the alternative fuel buses under normal transit operation routes from 2003 to 2009. These data included operational, performance, and maintenance statistics. Further, a detailed cost breakdown for each vehicle was available. These demonstration studies provided good data for this work because of their transparency, data availability, and regional diversity. Since these were demonstrations within the same NREL program, the methods and reporting metrics between the studies are consistent. These demonstration studies could provide a robust baseline to inform the expert systems based decision making model for the AFV transit environment; especially, if the uncertainty related to these LCA can be analyzed and quantified.

The (Haller et al, 2007) study showed the degree to which policy makers at Forest Preserve viewed alternative fuel vehicles as good candidates for fleet applications. The study results were discussed in terms of their impact for managerial practice in local government fleet agencies and for future research. At the time of the study, implementation issues associated with alternative fuel vehicles were not well understood even though they are an integral part of understanding the environmental benefits and economic impacts involve in fleet enhancement or conversion. This introduced a large amount of uncertainty into this investigation. It is clear that a further study of the uncertainty characteristics and propagation discussed in this study should be further investigated.

9.5 Improvements in Methods of Analysis to Enable Better Design and Decision Making in Fleet Use of Alternative Fuel Technologies

The study (Patil et al, 2010) was successful in highlighting the uncertainty that exists in the decision making process for alternative fuel buses. Most of the uncertainty that is described in the study focused on the technology and emissions requirements. This is consistent with the findings in (McKenzie et al, 2012) and (Haller et al, 2007).

In literature that I have reviewed on decision making, it is clear that the development of a methodology for addressing the increasing uncertainty in fleet management and planning is critical. In fact, the (McKenzie et al, 2012) and (Haller et al, 2007) studies limited the uncertainty to technology and emissions requirements in order to simplify and quantify the uncertainty solution space. For example, the discount rate methodology employed in (McKenzie et al, 2012) for both costs and emissions was found to be appropriate to offset the "uncertainty" associated with the use and adoption of new alternative fuel. Further, the (Haller et al, 2007) found that the uncertainty associated with the lack of understanding regarding implementation issues in technology associated with alternative fuel vehicles caused Forest Preserve to underperform in its anticipated savings.

These studies have greatly informed this research. The management of uncertainty within the decision making process is very important to better ensure decision quality; especially as the number of uncertainty variables are allow to grow.

The research represents my findings on the identification of how this improved research approach will enable better policy design and decision making. The proposed improvement that I anticipate in the policy arena depends upon slight improvements in the capabilities of program managers and policy staffs to translate this research into better policy and program practice. These improvements are anticipated largely in the area of decision making expert understanding of the uncertainty in the policy development arena and its impact on technology innovation.

9.6 Summary

This chapter provides an investigation on methods of analysis to enable better design in decision making in fleet use of alternative fuel technologies. The study in (McKenzie and Durango-Cohen, 2012), was presented to highlight the environmental life-cycle assessment of transit buses with alternative fuel technology; where, alternate fuels address environmental concerns due to their low tailpipe emissions relative to standard diesel fuel. Further, findings form this study were present that alternate fuel buses significantly reduce the cost of operation and tailpipe emissions while they increase life-cycle cost. Infrastructure costs must be taken into account when estimating the total life-cycle cost to deploy and operate these vehicles. Further, the study found that efficient bus choice is sensitive to Passenger demand, but only moderately sensitive to technological characteristics, and that the relative efficiency of compressed natural gas buses is more sensitive to changes in fuel prices than that of the other bus types.

This chapter presented a study of (Haller et al, 2007), which showed the Economic costs and environmental impacts of alternative fuel vehicle fleets in local government; where, high crude oil prices and increasing public awareness of the environmental impacts of carbon based vehicle emissions have heightened interest in the adoption and use of alternative fuel vehicles (AFV) as shown in (Energy Information Administration, 2006b); where, policy makers view alternative fuel vehicles as good candidates for fleet applications. This chapter presented the use of multi-year micro data on fuel usage, operational and capital expenditures, and mileage and emissions; where a further examination of conversion costs, infrastructure investments required, extent of user adoption and emissions reductions achieved were also presented.

A methodological LCA framework where two parameters; cost and Green House Gas (GHG) emissions, were captured for the manufacturing and operating processes of the four categories of alternative fuel buses under investigation; where, data for the study was gathered from a series of NREL demonstration studies at New York City Transit, Washington Metro Transit Agency, Alameda-Contra Costa Transit, Sunline Transit Agency and Connecticut Transit. The basic structure of the LCA methodology was derived from processes that represent supply-chain activities such as raw materials extraction, fuel pathway and energy generation characteristic for each type of vehicle. Finally, the results of the study showed that the fleet under investigation experienced a complex array of decision criteria, variability in the external environment, and slower than desired rate of conversion; where, a conversion rate of 50% of its fleet to bio-fuel technologies was achieved absent anticipated cost savings and emissions reductions due to a shortfall in expected savings for unsecured grant program opportunities to support the installation of fast fuel stations and other fueling infrastructure.

These studies have greatly informed the research for this dissertation. The management of uncertainty within the decision making process is very important to better ensure decision quality; especially as the number of uncertainty variables are allow to grow.

The research represents my findings on the identification of how this improved research approach will enable better policy design and decision making. The proposed improvement that I anticipate in the policy arena depends upon slight improvements in the capabilities of program managers and policy staffs to translate this research into better policy and program practice. These improvements are anticipated largely in the area of decision making expert understanding of the uncertainty in the policy development arena and its impact on technology innovation.

Chapter 10

PROTOTYPE DECISION MAKING SYSTEM

10.1 Introduction

In order to demonstrate the feasibility of the development of a decision making tool to aid and inform the decisions of the fleet manager regarding Alternate Fuel Vehicles (AFV), this research will present a prototype which models the interdependency of factors shown as important to the decision making process. In the work by Shahpar (Shahpar, 2010), the focus was to provide DART (Delaware Authority for Regional Transit) administration decision making support relative to its future fleet expansion processes. Moreover, this work focused on the degree at which DART could leverage new technologies to meet its ongoing transportation infrastructure needs.

The focus of the research for this dissertation expands these concepts to inform the decision making of the general transit agency community via the development of an expert systems resource based upon the EXSYS Corvid® software platform. This platform has been selected for its broad capability in capturing expert decision making data in and easy to understand user applicable format.

This prototype Exsys Corvid® based system can assist users in finding the appropriate alternative fuel bus that aligns with the desired fleet parameters and performance characteristics. The system would recommend a good fleet asset choice based on a number of industry expert-derived life-cycle and performance factors.

The selection of the fleet asset is based upon the assignment of weighting to various factors. Factors that indicate a good match with the needs of the overall bus fleet or the characteristics and robustness of the fleet infrastructure are very heavily weighted. Factors which are less important are less heavily weighted. The asset characteristics are based upon those that are "typical" for each type of alternative fuel bus. There can be a high degree of difference in life cycle cost, emissions estimation and performance among the various alternative fuel buses, and the decision making system recommendations are given only as suggestions and a starting point in selecting the appropriate bus asset. A listing of the life cycle cost and emissions estimation among the various alternative fuel buses is provided below:

LIFE-CYCLE COST AND EMISSION ESTIMATION

Capital Cost

Vehicle Cost

Infrastructure Cost
- Diesel (ULSD)
- Biodiesel
- CNG
- Hybrid diesel-electric

Operating Cost
- Fuel Cost
- Total Maintenance Cost
- Facility Maintenance Cost
- Compression Electricity Cost
- Battery Replacement Cost

Emissions Estimation

10.2 Scope of the Decision Making System

The direct user of this system is the transit fleet administrator or management team. The results can be used by the administrator and/or management team as a reliable input to refine their urban transit bus expansion decision making process. This study does not cover paratransit vehicles and focuses on recommendations for buses that are 40 passenger or greater.

The results of this system are valid under the following assumptions (Shahpar, 2010):

1. There is a correlation between the bus purchasing history/volume and the bus useful life (approximately 12 years)

2. The buses are all 40-ft in length, low floor designs, without elaborate equipment specifications.

3. The buses are operated at average national conditions, speed of 12.5 mph and annual mileage of 35,000

4. When B20 biodiesel is used, the whole depot is converted, and additional, separate, fuel tanks are not required

5. Driver and mechanic training costs are not considered, but mechanic time is considered in maintenance costs

6. Driver operational costs are not considered

7. Benefits such as emissions credits, fuel tax credit or subsidies for having alternative technology vehicles are not considered

8. 80 percent federal subsidy for bus procurement was considered

9. The maintenance costs are constant (in 2013 dollar terms) for the 12 year life, and all data are presented as 2013 dollars

10. The fuel prices are constant (in 2013 dollar terms) for 12 years

There are many factors that attribute to the decision making process for fleet asset acquisition. In the past, the decision making process to purchase a bus asset was based primarily upon cost. Currently, other external factors such as, challenging economic times, environmental stewardship, and technological development have informed and expanded the traditional decision making paradigm. In addition, energy independence has added a new dimension to the decision process. In order to develop a decisions making system, it is important to determine how these various factors should inform the decision making process. This can be achieved via an expert survey to establish a knowledge base which is consistent with the current thinking of industry experts. For this portion of this work, I will utilize the expert survey process which was define in the study by (Shahpar, 2010).

10.3 Shahpar Expert Survey

The Shahpar Study, presented an estimate the life-cycle cost and emissions of the dominant alternative-fuel buses in the U.S. transit fleet database. This comparative analysis of alternative-fuel buses can aid transit managers in making informed decisions. Although this analysis can support the decision making process, it is not an exclusive determining factor in the best option for bus purchase. Shahpar found that there are many other factors which are critical to inform the decision maker. Shahpar conducted a decision making survey tool to understand the relative importance of different factors on transit fleet expansion strategies. Within this survey instrument, Shahpar queried several influential experts regarding the decision process to rank (weight) various factors within the decision process. Shahpar developed the survey tool based upon the following steps:

1. Defining a set of goals and criteria
2. Designing a questionnaire
3. Selecting experts to participate in the survey
4. Performing the survey
5. Analyzing the results

10.4 Shahpar Expert Survey Objectives

The Shahpar study (Shahpar, 2010) states that public transportation agencies are heavily subsidized through the use of federal and states funds; where these resources are limited and regulated. Since 1970 through 1990, public transportation agencies focused more on procurement cost of new transit buses than any other factor. Recent external conditions including global warming, air pollution, sustainability and energy independence has developed the need to expand the factors of consideration. Further, this shift in the industry can be seen in the guidance provided by EPA regulations and federal legislations such as ISTEA, TEA-21 and SAFETEA-LU; where public transportation agencies are strongly encouraged to continue to consider procurement cost while considering the impact of environmental, energy efficiency and life-cycle cost factors of alternative-fuel buses in order to receive their annual grants. Traditionally, these grants have been used to assist State and local governmental authorities in purchasing buses, related equipment and to construct bus-related facilities.

Expert surveys provide a great mechanism for public transit agents to determine the relative importance of different criteria in urban transit bus purchasing processes. The results of the Shahpar expert survey reflects the rank of each criterion in this process. In this study, four major goals were defined as follows: environmental and social, economic, technological, and transportation. Then, twelve criteria were defined under these goals. Figure 10.1 shows the structure and relation of defined goals and criteria.

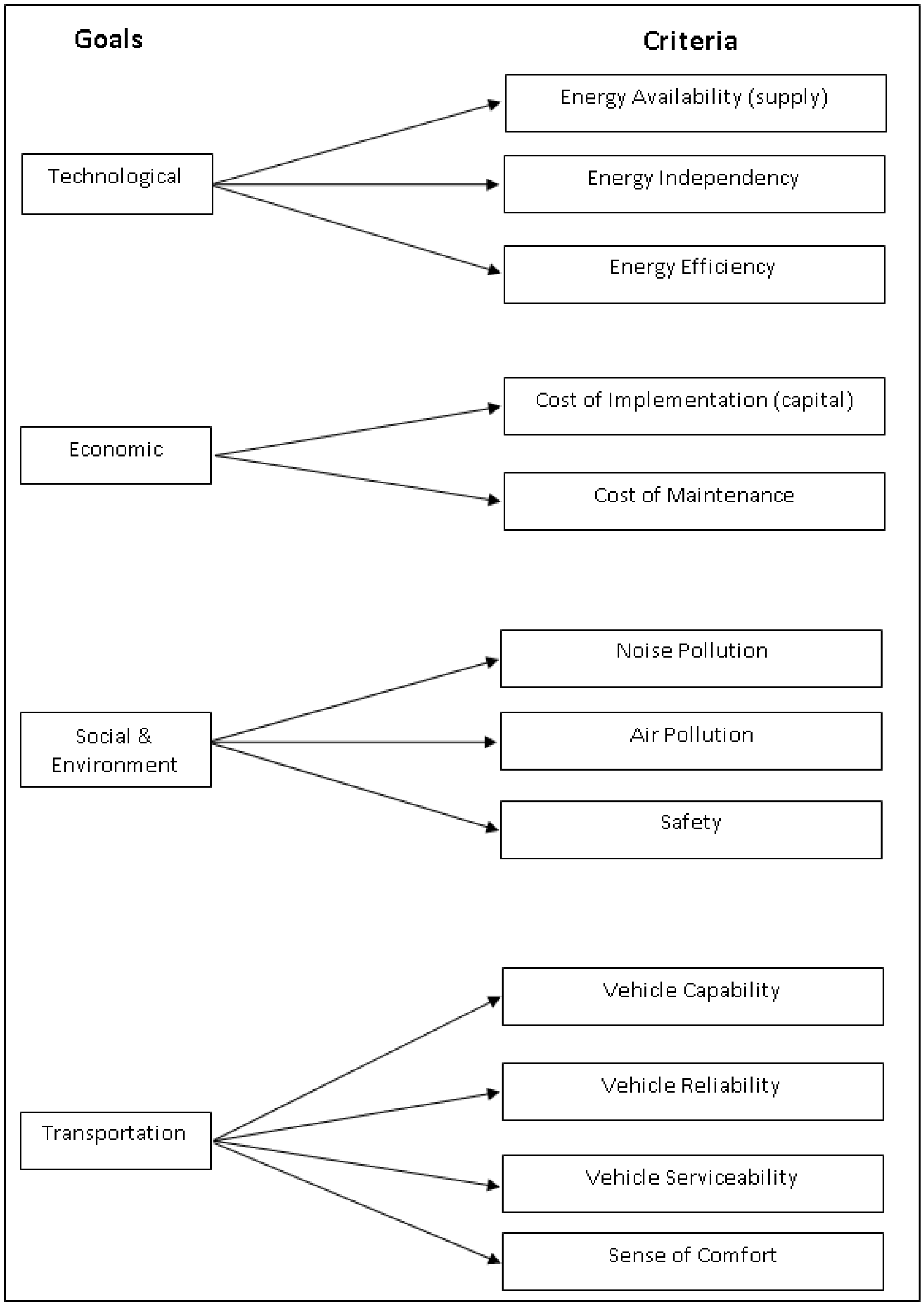


Figure 10.1: Structure and relation of defined goals and criteria (Shahpar, 2010)

10.5 Shahpar Expert Survey Evaluation Criteria

The Shahpar survey was designed to gather information from experts to evaluate the relative importance of the most viable alternative-fuel transit buses according to the predefined set of criteria. In order to evaluate the alternatives, the Shahpar study established twelve evaluation criteria as follows (Shahpar, 2010):

1. **Energy Availability**

   This criterion is based on the yearly amount of energy that can be supplied, on the reliability of energy supply, the reliability of energy storage, and on the cost of energy supply.

2. **Energy Independence**

   This criterion represents a condition in which a country is not beholden to foreign nations or fluctuations of the market in meeting its energy needs.

3. **Energy Efficiency**

   This criterion represents fuel economy of alternative-fuel buses.

4. **Costs of Implementation**

   This criterion refers to the costs of infrastructure (refueling stations and depot modifications) that each alternative demand.

5. **Costs of Maintenance**

   This criterion refers to the maintenance costs of alternative-fuel buses.

6. **Air Pollution**

   This criterion refers to the extent that a fuel mode contributes to air pollution.

7. **Noise Pollution**

   This criterion refers to the noise produced during the operation of the vehicle.

8. Safety

This criterion defines the importance of providing a safe way of transportation by public transportation agencies. Since some of alternative-fuels buses are not as common, safety characteristics of each fuel are not well known. The chemical composition and properties of each fuel change the way they are handled as compared to conventional diesel.

9. Vehicle Capability

This criterion represents the cruising distance, slope climbing, and average speed.

10. Vehicle Reliability

This criterion refers to the bus ability to stay in operation without breaking down. A measure of vehicle reliability is a roadcall, which is an on-road breakdown that would require a replacement bus to complete the route.

11. Vehicle Serviceability

This criterion defines preventive maintenance process that should be done in order to prevent a breakdown or failure. Serviceability measures can be taken in order to prevent roadcalls from occurring.

12. Sense of Comfort

This criterion refers to the particular issue regarding sense of comfort, and to the fact that users tend to pay attention to the accessories of the vehicle (air-conditioning, automatic door, etc.).

10.6 Shahpar Expert Survey Expert Selection

The selection of the appropriate industry experts is critical in the evaluation process. Informed and credible experts lend themselves to a more robust alternative-fuel bus decision making process. Within the Shahpar study, experts from manufacturing industries, related governmental agencies, academic and research institutes are acknowledged as credible experts. Table 10.1 shows the title and organization of the experts that where solicited and participated in the Shahpar survey.

Table 10.1: Title and organization of the targeted experts in the survey (Shahpar, 2010)

Respondent #	Organization	Title
1	Delaware Department of Transportation	Director of Planning
2		Planning Supervisor
3		Chief of Administration
4		Deputy Director, Planning
5		Project Planner
6		Project Planner
7		Financial and Policy Advisor
8	Delaware Transit Corporation	Executive Director
9		Procurement Manager
10		Maintenance & Tech. Manager
11		Planning Manager
12	Department of Natural Resources and Environmental Control	Planner for Air Quality Management
13		Environmental Program Administrator
14		Environmental Program Administrator
15	Wilmington Area Planning Council	Executive Director
16		Senior Planner
17		Principal Planner
18	Delaware Center for Transportation	Director
19		Engineer
20	Delaware Center for Fuel-Cell Research	Director
21	Energy Supplier	Business Development Manager
22	Bus Manufacturer	Business Development Manager

10.7 Shahpar Questionnaire

The Shahpar questionnaire (Shahpar, 2010) had the following characteristics:

1. The completion of questions takes fewer than 15 minutes

2. The questionnaire has four definitive parts where the questions were designed to provide anonymity to the respondent

    a. Part one asked three questions regarding to respondents' profession, type of work or research area, and their amount of experience.

    b. Part two asked one question in the form of a table where respondents were asked to rank the importance of the predefined criteria when a public transportation agency decided to acquire new transit buses regardless of their technology. Respondents provided rank order in the spaces provided using the numbers 1 (extremely important) through 12 (not very important). They were allowed to assign a same rank to more than one criterion.

    c. Part three also asked a question in form of a table. Respondents were asked to rank the performance of the alternatives in each criterion. Respondents provided rankings using the numbers 1 (being the best) through 4 (being the worst). The tables representing the results of this study also were provided in the questionnaire.

    d. Part four was optional and it provided a space for respondents to insert their opinions regarding to the usage of alternative-fuel transit buses in Delaware.

10.8 Shahpar Questionnaire Results Adapted to the Prototype Decision Making System

The expert respondents represented bus manufacturing, academia, energy supplier organizations, and research institutes. They assessed the relative importance (subjectively) for each of the criteria. Eight valid questionnaires were retrieved from the evaluation process.

The average values of weights and rank, based upon average weight value by criterion, are presented in table 10.2. These data suggest that the expert respondents felt that energy independence is the most important factor in evaluating the alternative vehicles; second in importance are energy availability and safety; third is energy efficiency, indicating the need for new alternative-fuel buses. Further, the study showed that the cost of maintenance criterion is more important than the cost of implementation criterion. In addition, the study showed that life-cycle cost is more important than capital cost. Vehicle related criteria such as vehicle reliability, capability, serviceability and sense comfort were shown to be less important. The Shahpar study suggests that the major reason for this result is that new transit buses are usually similar with respect to these criteria; therefore, it is assumed that the expert respondents gave these criteria low importance rankings for this reason.

Table 10.2: The average weights and ranks assigned by experts to each criterion (Shahpar, 2010)

Scale – 1 (extremely important) through 12 (not very important)

Criteria	Bus Manufacturer	Energy Supplier	Research Institutes	Academic Organizations	Average	Rank
Energy Availability	3	2	6	7	4.50	2
Energy Independence	6	1	4.5	5	4.13	1
Energy Efficiency	2	7	3.5	6	4.63	3
Cost of Implementation	5	9	5.5	1	5.13	5
Cost of Maintenance	4	8	4.5	3	4.88	4
Air Pollution	4	7	5	5	5.25	6
Noise Pollution	10	4	8.5	4	6.63	9
Safety	7	6	2	3	4.50	2
Vehicle Capability	5	8	5	7	6.25	8
Vehicle Reliability	4	8	6	4	5.50	7
Vehicle Serviceability	6	9	5.5	8	7.13	11
Sense of Comfort	8	5	6	9	7	10

The survey also asked the respondents to rank the alternatives with respect to each criterion. The evaluation results are presented in table 10.3.

Table 10.3: The relative importance of alternatives with respect to each criterion (Shahpar, 2010)

Scale - 1 (being the best) through 4 (being the worst)

Criteria	Ultra-Low Sulfur Diesel	Biodiesel	Compressed Natural Gas (CNG)	Hybrid Diesel-Electric
Energy Availability	2.5	3.75	2	1.75
Energy Independence	4	2.3	1.5	2.25
Energy Efficiency	2.75	3.5	2	1.75
Cost of Implementation	1.75	2.5	4	2
Cost of Maintenance	1	3	2.5	3.5
Air Pollution	3.5	3.5	1.5	1.5
Noise Pollution	3.5	3.5	1.75	1.25
Safety	2.75	2.75	2.95	1.75
Vehicle Capability	1.5	3.25	2.5	2.75
Vehicle Reliability	1	3.25	2.5	3.25
Vehicle Serviceability	1	3.25	2.5	3.25
Sense of Comfort	2.75	3.5	2	1.75

Table 10.4 below is the alternative-fuel bus ranks with respect to the criteria ranked in table 10.2.

Table 10.4: The relative importance ranks of the alternatives with respect to each criterion (adapted from Shahpar, 2010)

Criteria	Ultra-Low Sulfur Diesel	Biodiesel	Compressed Natural Gas (CNG)	Hybrid Diesel-Electric
Energy Availability	3	4	2	1
Energy Independence	4	3	1	2
Energy Efficiency	3	4	2	1
Cost of Implementation	1	3	4	2
Cost of Maintenance	1	3	2	4
Air Pollution	3	3	1	1
Noise Pollution	3	3	2	1
Safety	2	2	3	1
Vehicle Capability	1	4	2	3
Vehicle Reliability	1	3	2	3
Vehicle Serviceability	1	3	2	3
Sense of Comfort	3	4	2	1

In table 10.5, the ranks of the criterion multiplied by the relative importance of the alternatives with respect to each criterion. This relative importance of the alternatives with respect to each criterion provides a number which I refer to as the Impact Index (Y) for a given alternate fuel technology.

Table 10.5: The ranks of the criterion multiplied by the relative importance of the alternatives with respect to each criterion (adapted from Shahpar, 2010)

Criteria	Ultra-Low Sulfur Diesel	Biodiesel	Compressed Natural Gas (CNG)	Hybrid Diesel-Electric
(1) Energy Availability	6	8	4	2
(2) Energy Independence	4	3	1	2
(3) Energy Efficiency	9	12	6	3
(4) Cost of Implementation	5	15	20	10
(5) Cost of Maintenance	4	12	8	16
(6) Air Pollution	18	18	6	6
(7) Noise Pollution	27	27	18	9
(8) Safety	4	4	6	2
(9) Vehicle Capability	8	32	16	24
(10) Vehicle Reliability	7	21	14	21
(11) Vehicle Serviceability	11	33	22	33
(12) Sense of Comfort	30	40	20	10

This impact index (Y) number forms the basis for the weighting paradigm for the Exsys Corvid® based decision making system. A technology with a lower impact index (Y) number for a given criteria is more desirable. Specifically, the lower the (Y), the better that technology is perceived to perform in this criteria as reported by the experts survey respondents.

10.9 Summary

This chapter presented a decision making prototype which models the interdependency of factors shown as important to the decision making process to assist the bus fleet manager with Alternate Fuel Vehicle (AFV) technologies. This chapter leverages the work of Shahpar (Shahpar, 2010); where, the focus was to provide DART (Delaware Authority for Regional Transit) administration decision making support relative to its future fleet expansion processes and leveraged new technologies to meet its ongoing transportation infrastructure needs. Further, this chapter presented a Shahpar expert survey instrument, including the knowledge extraction process and results. These results were presented in the form of tables which capture the responses of the experts.

The focus of the research for this dissertation expands these concepts to inform the decision making of the general transit agency community via the development of an expert systems resource based upon the EXSYS Corvid® software platform.

In this chapter a concept was presented for the selection of the fleet asset based upon the assignment of weighting to various factors connected with life-cycle cost and emissions. Further, information was provided about the intended user of this system; where, the user, a transit fleet administrator or management team would use the system as a reliable input to refine their urban transit bus expansion decision making process under certain assumptions.

Finally, this chapter presented the concept of an impact index (Y) which is the ranks of the criterion multiplied by the relative importance of the alternatives with respect to each criterion. This (Y) forms the basis for the inference paradigm for the Exsys Corvid® based decision making system.

Chapter 11

EXSYS CORVID® BASED PROTOTYPE DECISION MAKING TOOL

11.1 Exsys Corvid® Based Prototype Decision Making Tool System Operation

The Exsys Corvid® development environment was chosen for the KBES prototype development process because of the power of the tool and the ease of use for the prototype developer. This tool provides a platform which allows for optimized and expert knowledge-based solutions through a powerful interactive web-enabled knowledge automation expert system.

Exsys Corvid® development software provides a novel process to build interactive Web applications that capture the logic and processes used to solve problems; where, the software and knowledge engineering are the result of over 28 years of enhancement, refinement and application to real-world problems (Exsys Inc., 2016). Proven across industry, government and military applications, Exsys is a world leader in knowledge automation expert systems.

Exsys Corvid® Expert System Development Tool

Exsys Corvid is a powerful tool for developing interactive expert system applications in a web-based format. It enables the decision making process and logic of the domain expert to be converted into a structured form that can be used by the Exsys

Inference Engine to drive interactive real time sessions that provide system level output in the form of advice to end users.

Corvid solves two (2) major issues in expert system development (Exsys Inc., 2016):

1. Capture of the decision making logic and process of the domain expert
2. Facilitation of a system user interface with the desired look-and-feel

Capturing the Decision Making Logic and Process

Corvid provides multiple ways to describe logic, so an appropriate approach for a problem can be used. Corvid uses "heuristic" If/Then rules based upon variables. There are 7 types of variables from fairly standard numeric and string variables to collection variables for dynamic reports or confidence variables that make it easy to build probabilistic systems. Variables have associated methods and properties allowing them to be used in many ways (Exsys Inc., 2016).

The rules in a system are just If/Then rules and algebra. Typically each rule represents a small step in a decision. Some rules may represent higher level logic, others may cover intermediate steps and be used to derive information used by the higher level rules (Exsys Inc., 2016).

<u>Logic Block</u>

A complex system may have many rules. Corvid uses Logic and Action Blocks to organize and structure the rules (Exsys Inc., 2016). Logic Blocks are a superset of tree diagrams, and allow groups of related rules to be organized to make them easier to build and maintain, and to show any gaps in the logic. Logic Blocks are very "free-form" and there are many ways to build the logic for a system. Action Blocks provide another way to build rules that are more procedural and aimed at "Smart Questionnaires"

Command Block

In addition to Logic and Action Blocks that contain the rules, Corvid has Command Blocks that describe the procedural flow of system execution. Command Blocks are more like a script, but also allow IF, WHILE and FOR loops.

Building the User Interface

Corvid systems can be run with either the Exsys Inference Engine as a Java Applet or a Java Servlet Runtime program. The Corvid Runtime uses the settings to control how questions will be asked and how results will be presented. When using the Applet Runtime, Corvid automatically generates all the files needed to field the system on a web server.

11.2 User Interface for the Exsys Corvid® Based Prototype Decision Making Tool

In order to interface with the prototype decision making tool, the user is asked a series of questions which are related to fleet characteristics and criteria. The answers to the questions are provided by the user in a real time interactive session. As described previously, the inputs (answers) provided at the user interface are processed by the inference engine in the Exsys Corvid platform as illustrated in Fig. 11.1 below; where the impact index (Y) values from Table 10.5 above are embedded in the system logic block labeled “Static Factor.” The rank calculation is the product of the user supplied answer (X), “Dynamic Factor”, and the impact index (Y) for each alternate fuel vehicle technology. This product is calculated for each alternate fuel vehicle technology for each of the criteria (b) highlighted in Table 10.5 and summed to create a value referred to as the Recommendation Score (R Score). The resulting equation for the rank (Logic Block) is as follows:

$$\text{R Score} = \sum_{b=1}^{12} (X_b * Y_b)$$

Although the Dynamic Factor is clearly defined for the prototype in this research, it is possible to provide an increased level of user customization within the user interface. In this way, the user would be provided a mechanism to view stepwise input impacts on the system output to allow for changes to input variables toward the achievement of a more desirable system level result.

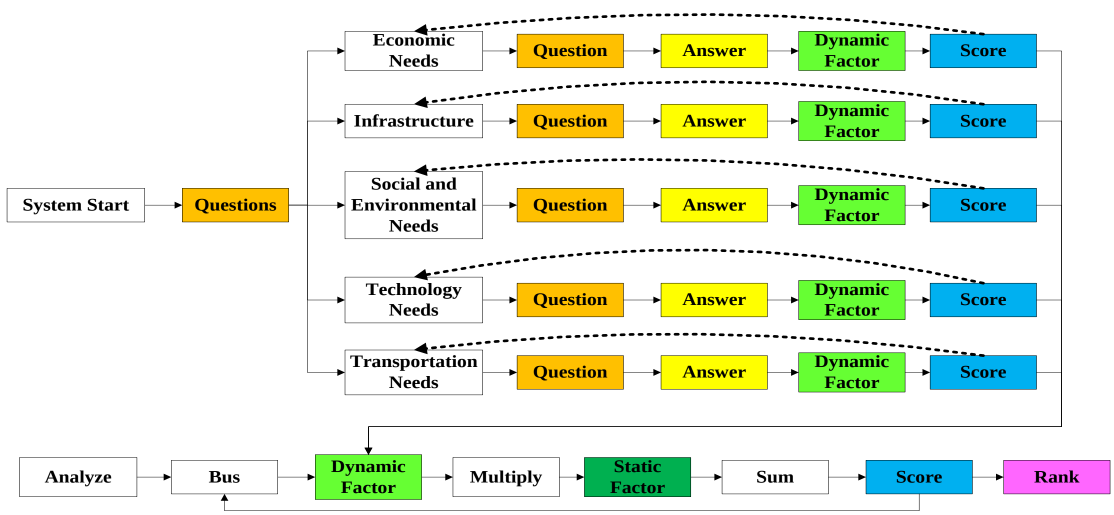


Figure 11.1: Flow diagram: Exsys Corvid® Based prototype decision making tool

There are system level logic blocks associated with each of the fleet characteristic factors embedded in the inference engine. To simplify the prototype system for a proof of concept, only the fleet infrastructure and fleet needs are active in the design of the inference engine logic blocks; however, questions are supplied for each characteristic for the user interface for future iterations of the program design. For the current prototype system, the fleet infrastructure and ridership inputs are normalized so that they have no impact on the system output; however, these inputs are captured and displayed in the system output for reference. In future versions of this prototype, it is possible to define weights to the fleet infrastructure and ridership inputs to impact the resulting R Score calculation. The fleet characteristics focus on the following:

1. Fleet Infrastructure
2. Fleet Ridership
3. Fleet Technology Needs
4. Fleet Economic Needs
5. Fleet Social & Environmental Needs
6. Fleet Transportation Needs

The questions (X) related to the fleet characteristics and criteria and are as follows:

I need to know about your overall Fleet Infrastructure

What is the total number of active buses in your fleet?

- <50
- 51–100
- 101–150
- 151–200

- 201-300
- >300

What is the average age of buses in your fleet?

- <5 years
- 5–10
- 11–15
- >15

What is the current percentage of alternative fuel buses in your fleet?

- <5%
- 5–10%
- 11–25%
- 26–50%
- >50%

What percentage of your buses are 40 passenger or greater?

- <5%
- 5–10%
- 11–25%
- 26–50%
- >50%

What percentage of your buses that are 40 passenger or greater are alternative fuel buses?

- <5%
- 5–10%
- 11–25%
- 26–50%
- >50%

I need to know about your overall Fleet Ridership

What is your overall ridership in passenger trips?

________________________ Million

Of your overall revenue, what is the percentage of each of the following?

State Funds ____________
Federal Funds ____________
Passenger Fares ____________
Bus Advertisement ____________

This potential bus purchase is intended:

- To expand the fleet
- To renew the fleet
- Both

I need to know about your overall Fleet Technology Needs

Some organizations have more energy availability than others. Would you say your organization's energy availability (supply, storage and cost of storage) is?

- High
- Medium
- Low

Some organizations have more energy independence than others. Would you say your organization's energy independence (resilience to pricing fluctuations) is?

- High
- Medium
- Low

Some buses are more energy efficient than others. Would you object to a bus that is less energy efficient?

- Yes
- No

I need to know about your overall Fleet Economic Needs

Some buses require more capital infrastructure than others. Would you object to a bus that requires more capital infrastructure (refueling stations and depot modification)?

- Yes
- No

Some Buses are more costly to maintain than others. Would you object to a bus that is more costly to maintain?

- Yes
- No

I need to know about your overall Fleet Social & Environmental Needs

Some buses produce more noise than others. Would you object to a bus that is less quiet?

- Yes
- No

Some buses produce more air pollution than others. Would you object to a bus that is less environmentally clean (contribution to air pollution)?

- Yes
- No

Some buses provided better safety than others. Would you object to a bus that is less safe (fuel handling properties compared to conventional diesel)?

- Yes
- No

I need to know about your overall Fleet Transportation Needs

Some buses are more capable than others. Would you object to a bus that is less capable (cruising distance, slope climbing and average speed)?

- Yes
- No

Some buses are more reliable than others. Would you object to a bus that is less reliable (on-road breakdown or roadcalls)?

- Yes
- No

Some buses require more service than others. Would you object to a bus that is less serviceable (preventive maintenance to prevent roadcalls)?

- Yes
- No

Some buses are more comfortable than others. Would you object to a bus that is less comfortable (user attention to accessories – i.e. air-conditioning, automatic door, etc.)?

- Yes
- No

11.3 Test and Evaluation of the Exsys Corvid® Based Prototype Decision Making Tool

The test and evaluation (T&E) of a KBES can involve various methods but the results should focus on the evaluation of certain critical factors of operation. Generally, the two activities which should be applied to the T&E methodology are verification and validation (V&V). This T&E philosophy has been widely held in the software industry for the past few decades. In its most basic form, verification is defined as a sequence of testing steps that determine whether the software meets certain established requirements at each phase of development. Further, validation is focused on the demonstration of the software to solve the predefined problem (El-Korany et al, 2000).

There are various recommended T&E methods which can be employed to assist KBES developers to design and measure system performance and correctness. Of the recommendations cited in (Faghri, 1989); where three recommendation are provided, it was determined that the recommendation involving a thorough testing at each of the evaluation checkpoints to inform any prototype system revisions or changes would be adopted.

The appendices in this dissertation contain information about the overall coding (Appendix A) and illustrative operation of the Exsys Corvid® Based Prototype Decision making Tool (Appendix B). The code and illustrative operation of the prototype system are provided in Appendices 1 and 2, respectively. As described above, T&E was performed at each phase of the design and build process which informed prototype system revisions or changes. To illustrate the prototype system in operation, an optimization was performed on the inference engine logic block to determine the inputs needed for a desired system output. Once the appropriate inputs where calculated, the system was run with the desired inputs and a verification of the system output was performed consistent with the expected output based upon the input optimization. Appendix B provides the verification process for two examples for the Hybrid Diesel Electric (HDE) and Compressed Natural Gas (GNG) vehicle recommendations, respectively.

For illustration, we will provide an explanation of this process using the HDE example.

HDE Example Illustration:

To illustrate the prototype system in operation, the optimization described above was performed on the inference engine logic block to estimate the inputs needed for a desired system output. In this example, the goal was to find the input combination that would yield an output or Recommendation Score (R Score) which would favor the HDE vehicle technology. Again, the lower the R Score the stronger the recommendation is for that alternate fuel technology. Figure 11.2 below illustrates the optimization results for this example; where, the optimized variable input values (X), the impact index values (Y) and the prototype system optimization constraints are shown. These constraints are based upon the inference engine weighting factors consistent with the answer fidelity within the system. For example, the questions on energy availability and energy independence are based upon a (high, medium, low) range; therefore, the constraint in calculating the optimization is 0.33 and the remaining questions are (Yes, No) range; therefore, the constraint in calculating the optimization is 0.50. The resulting output values (R Score) are the sum product of the X and Y for each alternative fuel vehicle (AFV) technology represented by the following equation:

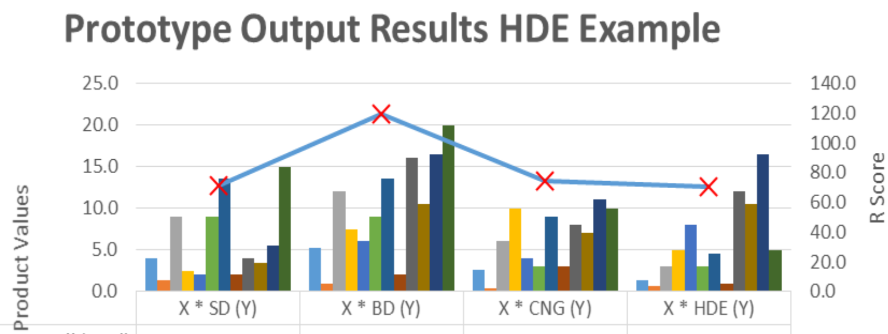
$$\text{R Score} = \sum_{b=1}^{12} (X_b * Y_b)$$

Table 11.1: Optimization results for the HDE example

Variable# (b)	Variable (X)	Factor (Variable)	SD (Y)	BD (Y)	CNG (Y)	HDE (Y)	Constraint	Constraint
1	0.66	Energy Avail (Med)	6	8	4	2	0.33	1
2	0.33	Energy Ind (Low)	4	3	1	2	0.33	1
3	1	Energy Eff (No)	9	12	6	3	0.5	1
4	0.5	Capital Infr (Yes)	5	15	20	10	0.5	1
5	0.5	Maint (Yes)	4	12	8	16	0.5	1
6	0.5	Noise (Yes)	18	18	6	6	0.5	1
7	0.5	Air Poll (Yes)	27	27	18	9	0.5	1
8	0.5	Safety (Yes)	4	4	6	2	0.5	1
9	0.5	Capable (Yes)	8	32	16	24	0.5	1
10	0.5	Reliable (Yes)	7	21	14	21	0.5	1
11	0.5	Service (Yes)	11	33	22	33	0.5	1
12	0.5	Comfort (Yes)	30	40	20	10	0.5	1
		R Score	71.28	119.27	73.97	70.48		

Note: SD, BD, CNG and HDE represents Sulfur Diesel, Bio-Diesel, Compressed Natural Gas and Hybrid Diesel Electric, respectively.

In fig 11.2 below, the products, $[X_b * (AFV)Y_b]$; where b = 1 to 12 , are shown. The summation of the products for each AFV (Alternate Fuel Vehicle) equals the R Score for that AFV.



	X * SD (Y)	X * BD (Y)	X * CNG (Y)	X * HDE (Y)
1 Energy Avail (Med)	4.0	5.3	2.6	1.3
2 Energy Ind (Low)	1.3	1.0	0.3	0.7
3 Energy Eff (No)	9.0	12.0	6.0	3.0
4 Capital Infr (Yes)	2.5	7.5	10.0	5.0
5 Maint (Yes)	2.0	6.0	4.0	8.0
6 Noise (Yes)	9.0	9.0	3.0	3.0
7 Air Poll (Yes)	13.5	13.5	9.0	4.5
8 Safety (Yes)	2.0	2.0	3.0	1.0
9 Capable (Yes)	4.0	16.0	8.0	12.0
10 Reliable (Yes)	3.5	10.5	7.0	10.5
11 Service (Yes)	5.5	16.5	11.0	16.5
12 Comfort (Yes)	15.0	20.0	10.0	5.0
R Score	71.3	119.3	74.0	70.5

Figure 11.2: Prototype product and output results (R Score)

Once the appropriate inputs where calculated, the system was run with the desired inputs and a verification of the system output was performed consistent with the expected output based upon the input optimization. Appendix B illustrates the actual screenshots from the operation of the prototype using these optimized input values (X_b) shown in Table 11.1.

11.4 Summary

This chapter presented the Exsys Corvid® development environment which was utilized for the KBES prototype process; where the platform allows for optimized and expert knowledge-based solutions through a powerful interactive Web-enabled knowledge automation expert system. Exsys Corvid is a powerful tool for developing interactive expert system applications in a web-based format. It enables the decision making process and logic of the domain expert to be converted into a structured form that can be used by the Exsys Inference Engine to drive interactive real time sessions that provide system level output in the form of advice to end users (Exsys Inc., 2016).

This chapter presented the user interface query design for the Exsys Corvid® based prototype decision making tool; where, the user is asked a series of questions which are related to fleet characteristic and needs criteria.

Finally, this chapter presented T&E method involving a thorough testing at each of the evaluation checkpoints to inform any prototype system revisions or changes.

The appendices in this dissertation contain information about the overall coding and illustrative operation of the Exsys Corvid® Based Prototype Decision making Tool.

Chapter 12

SUMMARY, CONCLUSION AND RECOMMENDATIONS

12.1 Summary

In summary, a methodology was presented to develop a decision making prototype strategy made possible through the use of the Exsys Corvid® prototype environment. An analysis of the Argonne Report was presented which is an important study which highlights the viability of the commercial intracity truck industry to take advantage of the benefits of natural gas (NG) technologies; where the demonstration of a long-term aggressive future market penetration of heavy-duty NG vehicles can be established. A summary of the USDOT Fuel Cell Bus Program which highlights the Alameda-Contra Costa Transit District (AC Transit) which operated revenue service buses within the FTA's National Fuel Cell Bus Program (NFCBP); where the testing acquired a knowledge base via operational data gathering to inform future design considerations through the identification and resolution of potential in-service anomalies and failures. A historical perspective on decision making modeling, the field of artificial intelligence (AI), the AI sub-field of knowledge-based expert systems (KBES) and the notion of uncertainty in decision making processes was presented. The concept of uncertainty in fuel availability and emissions was presented; where it is possible to develop design parameters to help policy makers develop a better knowledge-base of the impact of their decisions given real-world uncertainties in technology innovation and market changes in the coming decades. The concept of uncertainty in fuel pricing was presented based upon the volatility in the global fuel market due to a wide range of independent factors and variables. The concept of “cradle to grave” comprehensive analysis was presented as related to alternative fuels; where, a broad spectrum of environmental factors and/or attributes, which can be associated with products and services, support process development, influence policy and promote informed decision making. A process was presented to improve methods of analysis to enable better design and decision making in fleet use of alternative fuel technologies. An approach was presented to develop a prototype decision making system for the use in fleet management applications.

12.2 Conclusion

In the work by (Rukowicz, 2006), a comparative analysis was presented to evaluate alternative fuel and conventional diesel buses within a bus transit infrastructure. The work of (Shahpar, 2010), built upon the work of (Rukowicz, 2006) and limited the scope of these analyses to inform the fleet decision making at Delaware Authority for Regional Transit (DART). The Shahpar study found that among the eight alternative-fuel buses introduced by the Clean Air Act (CAA) of 1990, only CNG, biodiesel, and hybrid diesel-electric buses can be considered as viable alternatives for the Ultra-Low Sulfur Diesel (ULSD) transit buses. The Life-Cycle Cost (LCC) and emissions for each of these technologies are determined and compared with the available information for the ULSD buses.

This investigation includes, transit system industry review, industry expert survey instrument creation, expert data extraction and analysis, expert system development and other related factors.

Based on the findings of this research, I believe that the next generation of advancements in decision making tools will be in the area of the application of methods to quantify and manage uncertainty. In particular, the uncertainty that comes from the public policy arena where future policy and regulations are not always based upon logical and predictable processes. The fleet decision making process in most governmental agencies is a very complex and interdependent activity. There are always competing forces and agendas within the view of the decision maker. Rarely is the decision maker a single person although, within the transit environment, there is often one person charged with the responsibility of fleet management.

As industry decision experts begin to increasingly understand the relationship between their role and the impact on policy and technological development, this will help to quantify and contextualize the uncertainty associated with these complex systems. As a result, the analysis community will be able to use these inputs to inform their models to aid and inform overall decision making.

12.3 Recommendations

An approach was presented to develop a prototype decision making system for the use in bus fleet management applications. In this prototype, only CNG, biodiesel, and hybrid diesel-electric buses were considered as viable alternatives for the Ultra-Low Sulfur Diesel (ULSD) transit buses. The expert system survey response data was used from the Shahpar (Shahpar, 2010) study. It is suggested that the survey engagement of additional experts, utilizing the same basic survey structure, would provide additional bandwidth to these data and provide further fidelity and refinement to the prototype decision making system design.

The notion of uncertainty in decision making processes was presented based upon the study (Patil et al, 2010) which suggested that alternative bus technology holds great promise for cities, and by extension, municipalities and other governmental transit agencies; where there is interest in meeting very rigorous emissions reduction targets. In the prototype presented in this research, uncertainty was managed via a fixed input architecture of the Exsys Corvid® system. For example, uncertainty variables such as fuel pricing, maintenance cost and federal government subsidies where held constant for the sake of simplicity. It is suggested that future work in the design of a more robust prototype include a feature which allows user input of these and other uncertainty variables.

It is suggested that this study be extended to include other types of alternate fuel vehicles such as those described in (Bastani et al, 2012); where, the uncertainty in the total fuel use and life-cycle GHG (Green House Gas) emissions from U.S. light-duty vehicles was quantified, as well as, the major factors which contribute to fuel use and emissions were identified and ranked. This study presented a fleet development pathway which found an approximate 50% reduction in the fleet GHG emissions and roughly a 40% reduction in fuel use by 2050; however, there were large uncertainties. Much could be learned about the alternate fuel bus fleet scenario by studying and modeling other more mature fleet alternate fuel applications.

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Appendix A

DECISION MAKING MODEL FOR THE MANAGEMENT OF
TRANSIT SYSTEM ALTERNATE FUEL INFRASTRUCTURES

Author: Michael Vaughan & Samuel Harry

System Printout

Variables:

[col_Collection] Collection Variable Prompt: col_Collection

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[col_Collection2] Collection Variable Prompt: col_Collection2

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[conf_BD]
Confidence Variable Prompt: conf_BD
Calculation: Must be integer value Calculation Mode: Sum

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False

Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[conf_CNG]
Confidence Variable Prompt: conf_CNG
Calculation: Must be integer value Calculation Mode: Sum

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[conf_HDE]
Confidence Variable Prompt: conf_HDE
Calculation: Must be integer value Calculation Mode: Sum

Flags:

Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[conf_ULSD] Confidence Variable Prompt: conf_ULSD
Calculation: Must be integer value Calculation Mode: Sum

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[list_Active_Bus]
Static List Variable
Prompt: What is the total number of active buses in your fleet? Static List Values:
Less_than_50
Less than 50

51_to_100
51 to 100

101_to_150
101 to 150

201_to_300
201 to 300

More_than_300
More than 300

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Also Ask:
list_Bus_Age list_Alternative_Bus
Before Ask, display:
TEXT "I need to know about your overall Fleet Infrastructure" FORMAT:
SIZE=20 STYLE= After Ask, display:
IMAGE "Break.jpg"

[list_Air_Polution]
Static List Variable
Prompt: Some buses produce more air pollution than others. Would you object to a bus that is less environmentally clean (contribute to air pollution)?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:

Ask with: Radio Buttons Arrange: One item per line After Ask, display: IMAGE "Break.jpg"

[list_Alternative_Bus]
Static List Variable
Prompt: What percentage of your buses that are 50 passenger or greater are alternative fuel buses?
Static List Values: Less_than_5% Less than 5%

5_to_10%
5 to 10%

11_to_25%
11 to 25%

26_to_50%
26 to 50%

More_than_50%
More than 50%

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line

[list_Alternative_Fuel]
Static List Variable
Prompt: What is the current percentage of alternative fuel buses in your fleet?
Static List Values:
Less_than_5%
Less than 5%

5_to_10%
5 to 10%

11_to_25%
11 to 25%

26_to_50%
26 to 50%

More_than_50%
More than 50%

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Also Ask:
list_Bus_Size Before Ask, display:
TEXT "I need to know about your overall Fleet Infrastructure" FORMAT: SIZE=20 STYLE= After Ask, display:
IMAGE "Break.jpg"

[list_Bus_Age]
Static List Variable
Prompt: What is the average age of buses in your fleet? Static List Values:
Less_than_5_years
Less than 5 years

5_to_10_years
5 to 10 years

11_to_15_years
11 to 15 years

More_than_15_years

More than 15 years

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line After Ask, display: IMAGE "Break.jpg"

[list_Bus_Size]
Static List Variable
Prompt: What percentage of your buses are 40 passenger or greater? Static List Values:
less_than_5%
less than 5%

5_to_10%
5 to 10%

11_to_25%
11 to 25%

26_to_50%
26 to 50%

more_than_50%
more than 50%

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False

Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line

[list_Capability]
Static List Variable
Prompt: Some buses are more capable than others. Would you object to a bus that is less capable (cruising distance, slope climbing and average speed)?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Also Ask:

list_Reliability list_Serviceability list_Comfort
Before Ask, display:
TEXT "I need to know about your overall Fleet Transportation Needs"
FORMAT: SIZE=20 After Ask, display:
IMAGE "Break.jpg"

[list_Comfort]
Static List Variable

Prompt: Some buses are more comfortable than others. Would you object to a bus that is less comfortable (user attention to accessories - i.e. air-conditioning, automatic door, etc.)?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line

[list_Maintenance]
Static List Variable
Prompt: Some buses are more costly to maintain than others. Would you object to a bus that is more costly to maintain?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False

Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False

Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line

[list_Noise]
Static List Variable
Prompt: Some buses produce more noise than others. Would you object to a bus that is less quiet?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Also Ask:
list_Air_Polution list_Safety
Before Ask, display:
TEXT "I need to know about your overall Fleet Social & Environmental Needs"
FORMAT: S After Ask, display:
IMAGE "Break.jpg"

[list_NRG_Available]
Static List Variable
Prompt: Some organizations have more energy availability than others. Would you say your organization's energy availability (supply, storage and cost of storage) is?

Static List Values:
High
High

Medium

Medium

Low
Low

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Also Ask: list_NRG_Independence list_NRG_Efficient
Before Ask, display:
TEXT "I need to know about your overall Fleet Technology Needs" FORMAT: SIZE=20 ST After Ask, display:
IMAGE "Break.jpg"

[list_NRG_Efficient]
Static List Variable
Prompt: Some buses are more energy efficient than others. Would you object to a bus that is less energy efficient?
Static List Values:
Yes
Yes

No
No

Flags:

Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons

Arrange: One item per line

[list_NRG_Independence]
Static List Variable
Prompt: Some organizations have more energy independence than others. Would you say your organization's energy independence (resilience to pricing fluctuations) is?
Static List Values:
High
High

Medium
Medium

Low
Low

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line After Ask, display:
IMAGE "Break.jpg"

[list_NRG_Infrastructure]
Static List Variable
Prompt: Some buses require more capital infrastructure than others. Would you object to a bus that requires more capital infrastructure (refueling stations and depot modification)?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False

Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Also Ask:
list_Maintenance Before Ask, display:
TEXT "I need to know about your overall Fleet Economic Needs" FORMAT: FONT=SansS After Ask, display:
IMAGE "Break.jpg"

[list_Purpose]
Static List Variable
Prompt: This potential bus purpose is intended: Static List Values:
to_expand_the_fleet
to expand the fleet

to_renew_the_fleet
to renew the fleet

both_expand_and_renew_the_fleet

both expand and renew the fleet

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line Before Ask, display:
TEXT "   "

[list_Reliability]
Static List Variable
Prompt: Some buses are more reliable than others. Would you object to a bus that is less reliable (on-road breakdown or roadcalls)?
Static List Values:
Yes

Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line After Ask, display:
IMAGE "Break.jpg"

[list_Safety]
Static List Variable
Prompt: Some buses provide better safety than others. Would you object to a bus that is less safe (fuel handling properties compared to conventional diesel)?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line

[list_Serviceability]
Static List Variable
Prompt: Some buses require more service than others. Would you object to a bus that is less serviceable (Preventative maintenance to prevent roadcalls)?
Static List Values:
Yes
Yes

No
No

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False

In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False
Any number of values can be assigned

Display:
Ask with: Radio Buttons Arrange: One item per line After Ask, display: IMAGE "Break.jpg"

[num_Active_Bus]
Numeric Variable
Prompt: num_Active_Bus

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Air_Pollution]
Numeric Variable
Prompt: num_Air_Pollution

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Alternative_Bus]
Numeric Variable
Prompt: num_Alternative_Bus

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Alternative_Fuel]
Numeric Variable
Prompt: num_Alternative_Fuel

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False

Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Bus_Age] Numeric Variable Prompt: num_Bus_Age

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False

Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Bus_Size] Numeric Variable Prompt: num_Bus_Size

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Capability] Numeric Variable Prompt: num_Capability

Flags:
Always obtain a value: False Display with results: False Never Ask User: False

Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Checking] Numeric Variable Prompt: num_Checking

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False

In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Comfort] Numeric Variable Prompt: num_Comfort

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Federal_Funds] Numeric Variable Prompt: Federal Funds

Flags:
Always obtain a value: False Display with results: True Never Ask User: False Display with results: True Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Fuel_Price]
Numeric Variable
Prompt: What is the current price of gasoline per gallon?
[num_Maintenance]
Numeric Variable
Prompt: num_Maintenance

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Noise]
Numeric Variable Prompt: num_Noise

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False

Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_NRG_Available]
Numeric Variable
Prompt: num_NRG_Available

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_NRG_Efficient]
Numeric Variable
Prompt: num_NRG_Efficient

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_NRG_Independence]
Numeric Variable
Prompt: num_NRG_Independence

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_NRG_Intrastructure]
Numeric Variable
Prompt: num_NRG_Intrastructure

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False

Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Other]
Numeric Variable Prompt: Other Funds

Flags:
Always obtain a value: False Display with results: True Never Ask User: False Display with results: True Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False

Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line After Ask, display:
IMAGE "Break.jpg"

[num_Reliability] Numeric Variable Prompt: num_Reliability

Flags:
Always obtain a value: False Display with results: False Never Ask User: False Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Ridership] Numeric Variable Prompt:

[num_Safety]
Numeric Variable Prompt: num_Safety

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_Serviceability]
Numeric Variable
Prompt: num_Serviceability

Flags:
Always obtain a value: False Display with results: False Never Ask User: False
Display with results: False Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:
Ask with: Edit Box Arrange: One item per line

[num_State_Funds] Numeric Variable Prompt: State Funds

Flags:
Always obtain a value: False Display with results: True Never Ask User: False
Display with results: True Initialize: False
Check for PARAM data passed in Applet call: False
In backward chaining, stop after first value is set: False In backward chaining, skip redundant rules: False
Use backward chaining to derive value: True Use External Source to get value: False

Display:

Ask with: Edit Box Arrange: One item per line Also Ask:
num_Federal_Funds num_Other
Before Ask, display:
TEXT "Of your overall funding, what percentage is each of the following?"
FORMAT: SIZE TEXT "Please ensure values sum to 100"
TEXT "Please do NOT include percent sign"

Logic Block: Logic Fleet Economic Needs

1 list_NRG_Infrastructure = Yes
2 --> [num_NRG_Independence] = 0.5
3 list_NRG_Infrastructure = No
4 --> [num_NRG_Independence] = 1.0
5 list_Maintenance = Yes
6 --> [num_Maintenance] = 0.5
7 list_Maintenance = No
8 --> [num_Maintenance] = 1.0

Logic Block: Logic Fleet Infrastructure

1 list_Active_Bus = Less_than_50
2 --> [num_Active_Bus] = 0
3 list_Active_Bus = 51_to_100
4 --> [num_Active_Bus] = 0
5 list_Active_Bus = 101_to_150
6 --> [num_Active_Bus] = 0
7 list_Active_Bus = 201_to_300
8 --> [num_Active_Bus] = 0
9 list_Active_Bus = More_than_300
10 --> [num_Active_Bus] = 0
11 list_Alternative_Bus = Less_than_5%
12 --> [num_Alternative_Bus] = 0
13 list_Alternative_Bus = 5_to_10%
14 --> [num_Alternative_Bus] = 0
15 list_Alternative_Bus = 11_to_25%
16 --> [num_Alternative_Bus] = 0
17 list_Alternative_Bus = 26_to_50%
18 --> [num_Alternative_Bus] = 0

```
list_Alternative_Bus = More_than_50%
--> [num_Alternative_Bus] = 0
list_Alternative_Fuel = Less_than_5%
--> [num_Alternative_Fuel] = 0
list_Alternative_Fuel = 5_to_10%
--> [num_Alternative_Fuel] = 0
list_Alternative_Fuel = 11_to_25%
--> [num_Alternative_Fuel] = 0
list_Alternative_Fuel = 26_to_50%
--> [num_Alternative_Fuel] = 0
list_Alternative_Fuel = More_than_50%
--> [num_Alternative_Fuel] = 0
list_Bus_Age = Less_than_5_years
--> [num_Bus_Age] = 0
list_Bus_Age = 5_to_10_years
--> [num_Bus_Age] = 0
list_Bus_Age = 11_to_15_years
--> [num_Bus_Age] = 0
list_Bus_Age = More_than_15_years
--> [num_Bus_Age] = 0
list_Bus_Size = less_than_5%
--> [num_Bus_Size] = 0
list_Bus_Size = 5_to_10%
--> [num_Bus_Size] = 0
list_Bus_Size = 11_to_25%
--> [num_Bus_Size] = 0
list_Bus_Size = 26_to_50%
--> [num_Bus_Size] = 0
list_Bus_Size = more_than_50%
```



```
--> [num_Bus_Size] = 0
```

Logic Block: Logic Fleet Social and Environmental Needs

```
list_Noise = Yes
--> [num_Noise] = 0.5
list_Noise = No
--> [num_Noise] = 1.0
list_Air_Polution = Yes
```

```
--> [num_Air_Pollution] = 0.5
list_Air_Polution = No
--> [num_Air_Pollution] = 1.0
list_Safety = Yes
--> [num_Safety] = 0.5
list_Safety = No
--> [num_Safety] = 1.0
```

Logic Block: Logic Fleet Technology Needs

```
list_NRG_Available = High
--> [num_NRG_Available] = 0.33
list_NRG_Available = Medium
--> [num_NRG_Available] = 0.66
list_NRG_Available = Low
--> [num_NRG_Available] = 1.0
list_NRG_Independence = High
--> [num_NRG_Independence] = 0.33
list_NRG_Independence = Medium
--> [num_NRG_Independence] = 0.66
list_NRG_Independence = Low
--> [num_NRG_Independence] = 1.0
list_NRG_Efficient = Yes
--> [num_NRG_Efficient] = 0.5
list_NRG_Efficient = No
--> [num_NRG_Efficient] = 1.0
```

Logic Block: Logic Fleet Transportation Needs

```
list_Capability = Yes
--> [num_Capability] = 0.5
list_Capability = No
--> [num_Capability] = 1.0
list_Reliability = Yes
--> [num_Reliability] = 0.5
list_Reliability = No
--> [num_Reliability] = 1.0
list_Serviceability = Yes
--> [num_Serviceability] = 0.5
list_Serviceability = No
```

```
12	--> [num_Serviceability] = 1.0
13	list_Comfort = Yes
14	--> [num_Comfort] = 0.5
15	list_Comfort = No
16	--> [num_Comfort] = 1.0
```

Command Block: Command Main

```
1	TITLE
2	FORWARD BLOCK=Logic Fleet Infrastructure
3	ASK [num_Ridership]
4	SET  [num_Checking]  [num_Federal_Funds] + [num_State_Funds] +
[num_Other]
5	WHILE [num_Checking] != 100
6	RESET [num_State_Funds]
7	RESET [num_Federal_Funds]
8	RESET [num_Other]
9	ASK   [num_State_Funds]
10	SET  [num_Checking]  [num_Federal_Funds] + [num_State_Funds] +
[num_Other]
11	// WHILE End
12	FORWARD BLOCK=Logic Fleet Technology Needs
13	FORWARD BLOCK=Logic Fleet Economic Needs
14	FORWARD BLOCK=Logic Fleet Social and Environmental Needs
15	FORWARD BLOCK=Logic Fleet Transportation Needs
16	SET   [conf_BD]   8 * [num_NRG_Available] + 3 *
[num_NRG_Independence] + 12 * [num_NRG_Efficient]   +
15*[num_NRG_Intrastructure]+12*[num_Maintenance]+18   *
[num_Air_Pollution] + 27 * [num_Noise] + 4 * [num_Safety] + 32 *
[num_Capability] + 21 * [num_Reliability] + 33 * [num_Serviceability] + 40 *
[num_Comfort]
17	SET   [conf_CNG]   4 * [num_NRG_Available] + 1 *
[num_NRG_Independence] + 6 * [num_NRG_Efficient] + 20 *
[num_NRG_Intrastructure] + 8 * [num_Maintenance] + 6 * [num_Air_Pollution]
+ 18 * [num_Noise] + 6 * [num_Safety] + 16 * [num_Capability] + 14 *
[num_Reliability] + 22 * [num_Serviceability] + 20 * [num_Comfort]
18	SET   [conf_HDE]   2 * [num_NRG_Available] + 2 *
[num_NRG_Independence] + 3 * [num_NRG_Efficient] + 10 *
[num_NRG_intrastructure] + 16* [num_Maintenance] + 6
```

```
*	[num_Air_Pollution] + 9 * [num_Noise] + 2 * [num_Safety] + 24 *
[num_Capability] + 21 * [num_Reliability] + 33 * [num_Serviceability] + 10 *
[num_Comfort]
19	SET   [conf_ULSD]   6 * [num_NRG_Available] + 4 *
[num_NRG_Independence] + 9 * [num_NRG_Efficient] + 5 *
[num_NRG_intrastructure] + 4 * [num_Maintenance] + 18 *
[num_Air_Pollution] + 27 * [num_Noise] + 4 * [num_Safety] + 8 *
[num_Capability] + 7
*	[num_Reliability] + 11 * [num_Serviceability] + 30 * [num_Comfort]
20	SET  [col_Collection.ADDSORTED]  Biodiesel Bus System: Score
[[conf_BD]] <BR> Description of biodiesel bus system, [conf_BD]
21	SET [col_Collection2.ADDSORTED] <IMG SRC="BD.jpg">, [conf_BD]
22	SET  [col_Collection.ADDSORTED]  Compressed Natural Gas Bus
System: Score [[conf_CNG]] <BR> Description of compressed natural gas bus
system, [conf_CNG]
23	SET [col_Collection2.ADDSORTED] <IMG SRC="CNG.jpg">,
[conf_CNG]
24	SET  [col_Collection.ADDSORTED]  Hybrid Diesel-Electric Bus System:
Score [[conf_HDE]] <BR> Description of hybrid diesel-electric bus system,
[conf_HDE]
25	SET [col_Collection2.ADDSORTED] <IMG SRC="HE.jpg">,
[conf_HDE]
26	SET  [col_Collection.ADDSORTED]  Ultra Low Sulfur Diesel Bus
System: Score [[conf_ULSD]] <BR> Description of ultra low sulfur diesel bus
system, [conf_ULSD]
27	SET [col_Collection2.ADDSORTED] <IMG SRC="SD.jpg">,
[conf_ULSD]
28	RESULTS
```

Appendix B

SCREEN SHOT SEQUENCE OF EXSYS CORVID ® PROTOTYPE DECISION MAKING MODEL FOR THE MANAGEMENT OF TRANSIT SYSTEM ALTERNATE FUEL INFRASTRUCTURES

B.1. Hybrid Diesel Electric (HDE) Example

Decision Making Model for the Management of
Transit System Alternate Fuel Infrastructures

This Corvid Exsys based system can assist users in finding the appropriate alternative fuel bus that aligns with the desired fleet parameters and performance characteristics. The system would recommend a good fleet asset choice based on a number of industry expert-derived life-cycle and performance factors. The selection of the fleet asset is based on weighting various factors. Factors that indicate a good match with the needs of the overall bus fleet or the characteristics and robustness of the fleet infrastructure are very heavily weighted. Factors which are less important are less heavily weighted. The asset characteristics are based upon those that are "typical" for each type of alternative fuel bus. There can be a great deal of difference in life cycle cost, emissions estimation and performance among the various alternative fuel buses, and the decision-making system recommendations are given only as suggestions and a starting point in selecting the appropriate bus asset.

OK

Exsys

I need to know about your overall Fleet Infrastructure

What is the total number of active buses in your fleet?

- ○ Less than 50
- ◉ 51 to 100
- ○ 101 to 150
- ○ 201 to 300
- ○ More than 300

What is the average age of buses in your fleet?

- ○ Less than 5 years
- ○ 5 to 10 years
- ○ 11 to 15 years
- ◉ More than 15 years

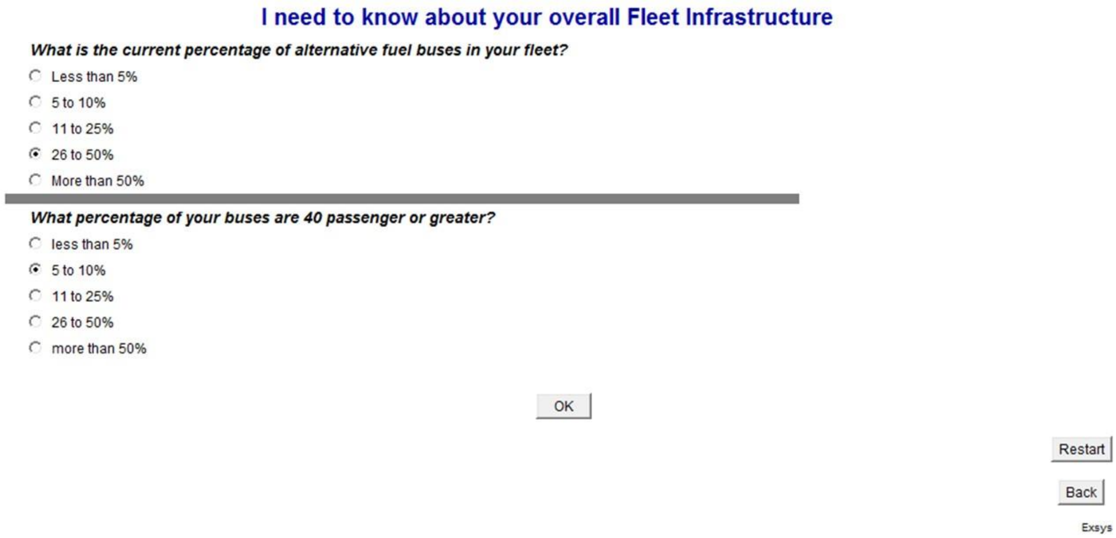
What percentage of your buses that are 50 passenger or greater are alternative fuel buses?

- ○ Less than 5%
- ○ 5 to 10%
- ○ 11 to 25%
- ○ 26 to 50%
- ◉ More than 50%

OK

Restart

Exsys



I need to know about your overall Fleet Infrastructure

What is the current percentage of alternative fuel buses in your fleet?

- ( ) Less than 5%
- ( ) 5 to 10%
- ( ) 11 to 25%
- (•) 26 to 50%
- ( ) More than 50%

What percentage of your buses are 40 passenger or greater?

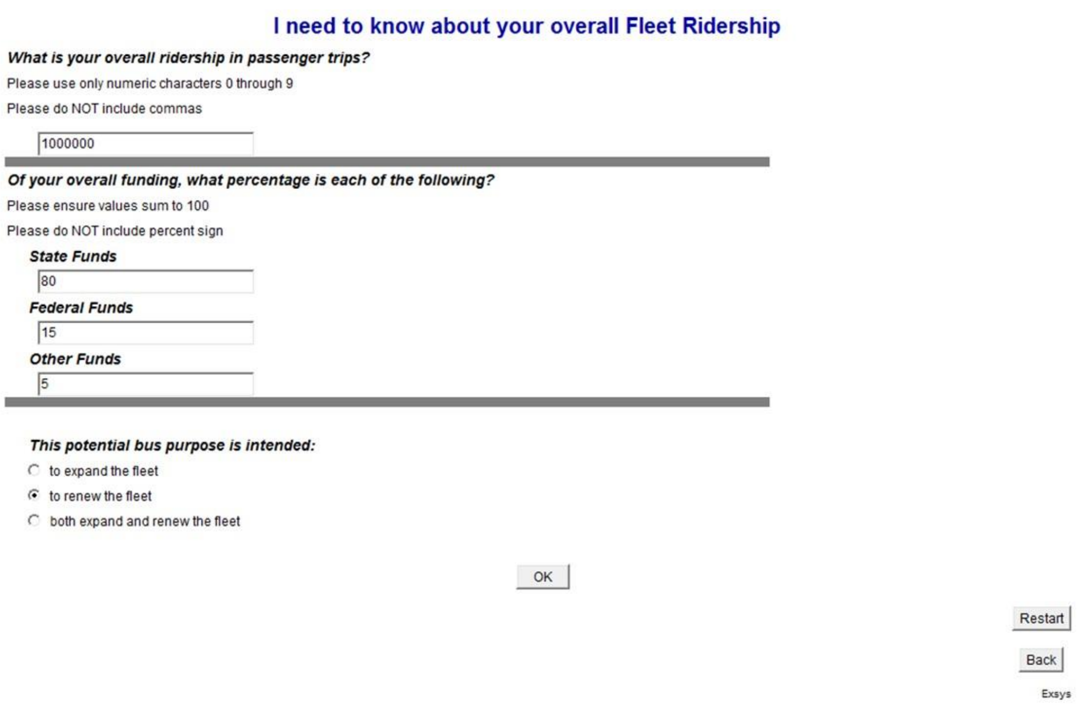
- ( ) less than 5%
- (•) 5 to 10%
- ( ) 11 to 25%
- ( ) 26 to 50%
- ( ) more than 50%

OK

Restart

Back

Exsys



I need to know about your overall Fleet Ridership

What is your overall ridership in passenger trips?

Please use only numeric characters 0 through 9

Please do NOT include commas

1000000

Of your overall funding, what percentage is each of the following?

Please ensure values sum to 100

Please do NOT include percent sign

State Funds

80

Federal Funds

15

Other Funds

5

This potential bus purpose is intended:

- ( ) to expand the fleet
- (•) to renew the fleet
- ( ) both expand and renew the fleet

OK

Restart

Back

Exsys

I need to know about your overall Fleet Technology Needs

Some organizations have more energy availability than others. Would you say your organization's energy availability (supply, storage and cost of storage) is?

- ( ) High
- (•) Medium
- ( ) Low

Some organizations have more energy independence than others. Would you say your organization's energy independence (resilience to pricing fluctuations) is?

- ( ) High
- ( ) Medium
- (•) Low

Some buses are more energy efficient than others. Would you object to a bus that is less energy efficient?

- ( ) Yes
- (•) No

OK

Restart

Back

Exsys

I need to know about your overall Fleet Economic Needs

Some buses require more capital infrastructure than others. Would you object to a bus that requires more capital infrastructure (refueling stations and depot modification)?

- (•) Yes
- ( ) No

Some buses are more costly to maintain than others. Would you object to a bus that is more costly to maintain?

- (•) Yes
- ( ) No

OK

Restart

Back

Exsys

I need to know about your overall Fleet Social & Environmental Needs

Some buses produce more noise than others. Would you object to a bus that is less quiet?

(•) Yes

( ) No

Some buses produce more air pollution than others. Would you object to a bus that is less environmentally clean (contribute to air pollution)?

(•) Yes

( ) No

Some buses provide better safety than others. Would you object to a bus that is less safe (fuel handling properties compared to conventional diesel)?

(•) Yes

( ) No

OK

Restart

Back

Exsys

I need to know about your overall Fleet Transportation Needs

Some buses are more capable than others. Would you object to a bus that is less capable (cruising distance, slope climbing and average speed)?

(•) Yes

( ) No

Some buses are more reliable than others. Would you object to a bus that is less reliable (on-road breakdown or roadcalls)?

(•) Yes

( ) No

Some buses require more service than others. Would you object to a bus that is less serviceable (Preventative maintenance to prevent roadcalls)?

(•) Yes

( ) No

Some buses are more comfortable than others. Would you object to a bus that is less comfortable (user attention to accessories - i.e. air-conditioning, automatic door, etc.)?

(•) Yes

( ) No

OK

Restart

Back

Exsys

Recommendations

For a bus fleet which intends to to renew the fleet, with:

1000000.0 passengers
15.0% federal funds
80.0% state funds
5.0% other funds
51 to 100 active buses
Average bus age of More than 15 years
26 to 50% alternative fuel buses
More than 50% alternative fuel buses of 50 passenger or greater
5 to 10% buses 40 passenger or greater

Hybrid Diesel-Electric Bus System: Score 70.0
Description of hybrid diesel-electric bus system

Ultra Low Sulfur Diesel Bus System: Score 71.0
Description of ultra low sulfur diesel bus system

Compressed Natural Gas Bus System: Score 74.0
Description of compressed natural gas bus system

Biodiesel Bus System: Score 119.0
Description of biodiesel bus system

B.2. Compressed Natural Gas (CNG) Example

Decision Making Model for the Management of Transit System Alternate Fuel Infrastructures

This Corvid Exsys based system can assist users in finding the appropriate alternative fuel bus that aligns with the desired fleet parameters and performance characteristics. The system would recommend a good fleet asset choice based on a number of industry expert-derived life-cycle and performance factors. The selection of the fleet asset is based on weighting various factors. Factors that indicate a good match with the needs of the overall bus fleet or the characteristics and robustness of the fleet infrastructure are very heavily weighted. Factors which are less important are less heavily weighted. The asset characteristics are based upon those that are "typical" for each type of alternative fuel bus. There can be a great deal of difference in life cycle cost, emissions estimation and performance among the various alternative fuel buses, and the decision-making system recommendations are given only as suggestions and a starting point in selecting the appropriate bus asset.

OK

Exsys

I need to know about your overall Fleet Infrastructure

What is the total number of active buses in your fleet?

- ○ Less than 50
- ○ 51 to 100
- ◉ 101 to 150
- ○ 201 to 300
- ○ More than 300

What is the average age of buses in your fleet?

- ○ Less than 5 years
- ○ 5 to 10 years
- ◉ 11 to 15 years
- ○ More than 15 years

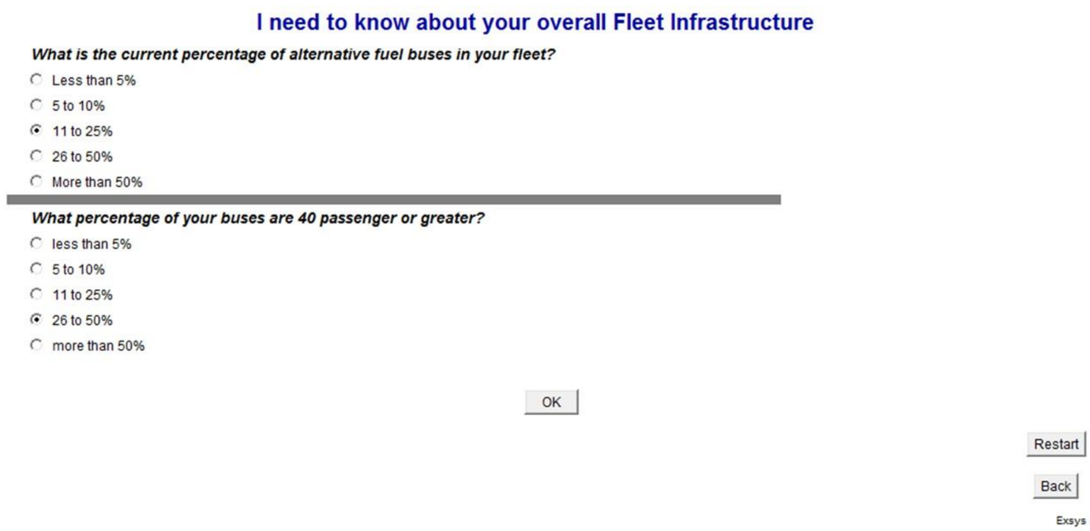
What percentage of your buses that are 50 passenger or greater are alternative fuel buses?

- ○ Less than 5%
- ◉ 5 to 10%
- ○ 11 to 25%
- ○ 26 to 50%
- ○ More than 50%

OK

Restart

Exsys



I need to know about your overall Fleet Infrastructure

What is the current percentage of alternative fuel buses in your fleet?

- ○ Less than 5%
- ○ 5 to 10%
- ◉ 11 to 25%
- ○ 26 to 50%
- ○ More than 50%

What percentage of your buses are 40 passenger or greater?

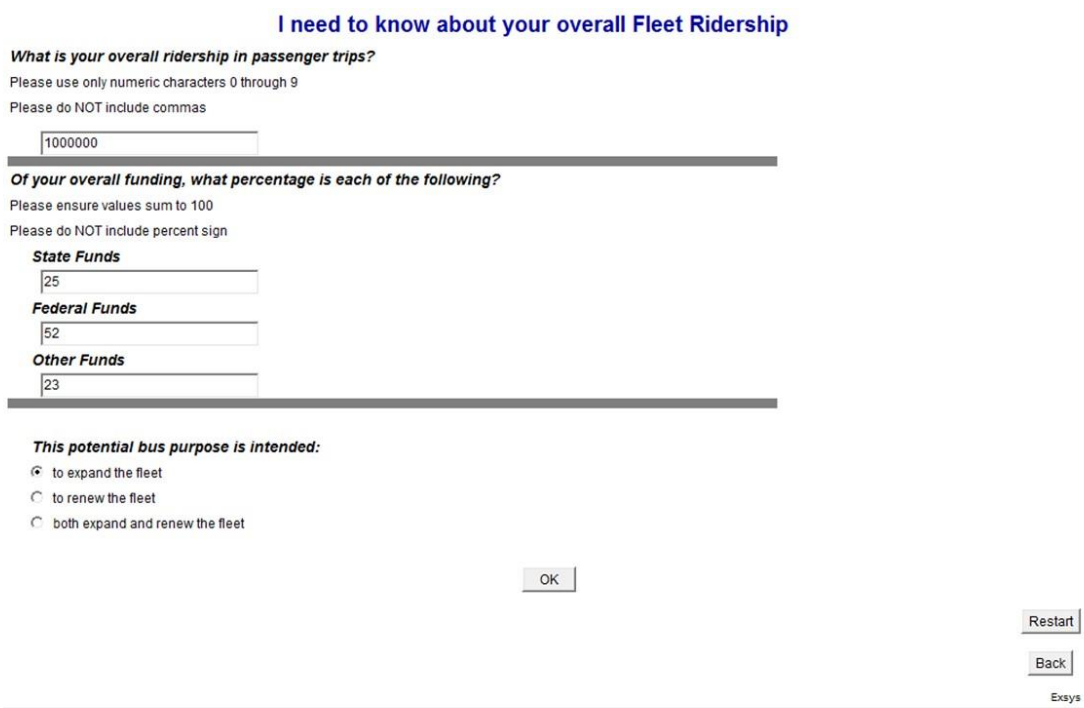
- ○ less than 5%
- ○ 5 to 10%
- ○ 11 to 25%
- ◉ 26 to 50%
- ○ more than 50%

OK

Restart

Back

Exsys



I need to know about your overall Fleet Ridership

What is your overall ridership in passenger trips?

Please use only numeric characters 0 through 9

Please do NOT include commas

1000000

Of your overall funding, what percentage is each of the following?

Please ensure values sum to 100

Please do NOT include percent sign

State Funds

25

Federal Funds

52

Other Funds

23

This potential bus purpose is intended:

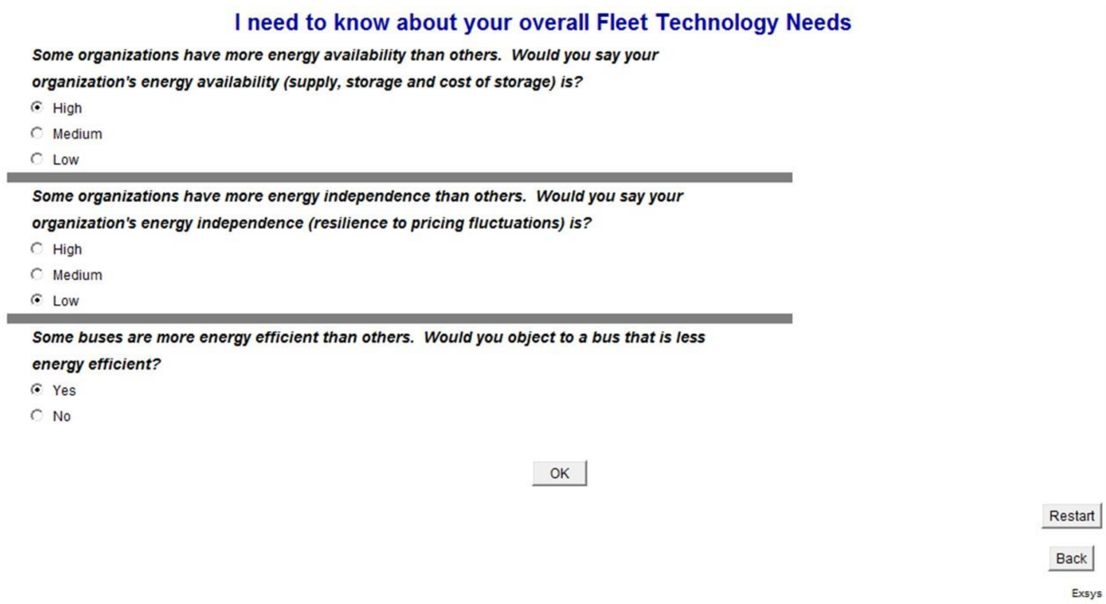
- ◉ to expand the fleet
- ○ to renew the fleet
- ○ both expand and renew the fleet

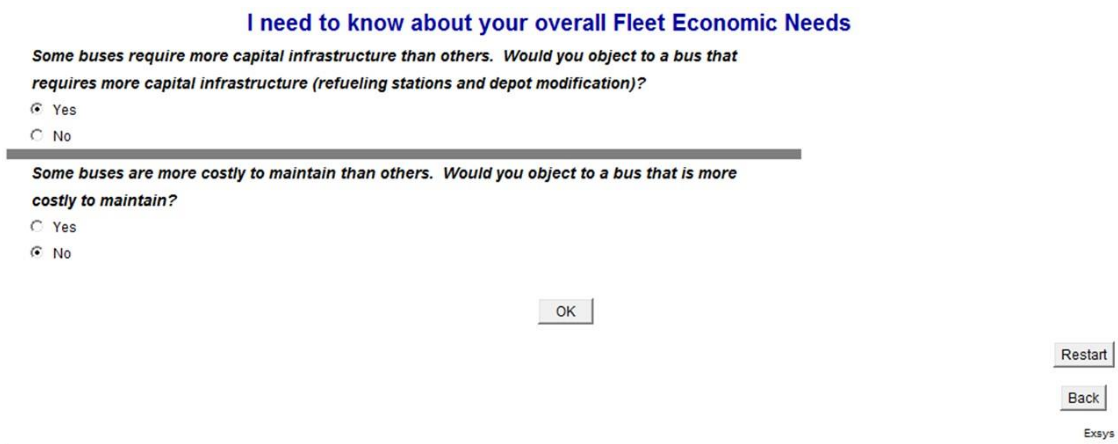
OK

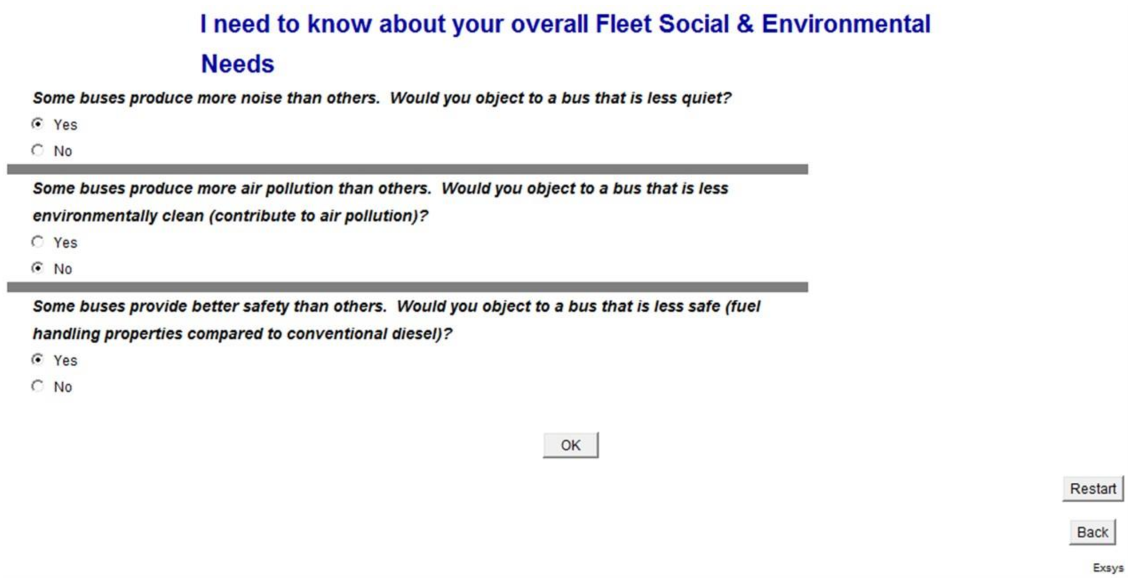
Restart

Back

Exsys


I need to know about your overall Fleet Technology Needs
Some organizations have more energy availability than others. Would you say your organization's energy availability (supply, storage and cost of storage) is?
High
Medium
Low
Some organizations have more energy independence than others. Would you say your organization's energy independence (resilience to pricing fluctuations) is?
High
Medium
Low
Some buses are more energy efficient than others. Would you object to a bus that is less energy efficient?
Yes
No
OK
Restart
Back
Exsys


I need to know about your overall Fleet Economic Needs
Some buses require more capital infrastructure than others. Would you object to a bus that requires more capital infrastructure (refueling stations and depot modification)?
Yes
No
Some buses are more costly to maintain than others. Would you object to a bus that is more costly to maintain?
Yes
No
OK
Restart
Back
Exsys



I need to know about your overall Fleet Social & Environmental Needs

Some buses produce more noise than others. Would you object to a bus that is less quiet?

(•) Yes
( ) No

Some buses produce more air pollution than others. Would you object to a bus that is less environmentally clean (contribute to air pollution)?

( ) Yes
(•) No

Some buses provide better safety than others. Would you object to a bus that is less safe (fuel handling properties compared to conventional diesel)?

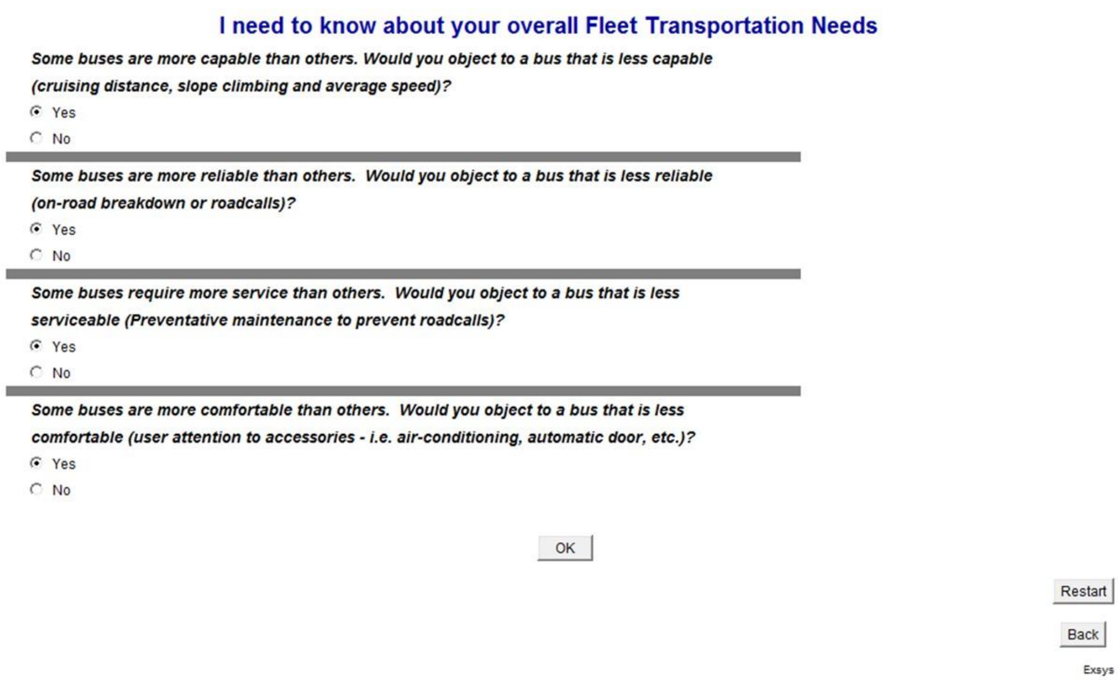
(•) Yes
( ) No

OK

Restart

Back

Exsys



I need to know about your overall Fleet Transportation Needs

Some buses are more capable than others. Would you object to a bus that is less capable (cruising distance, slope climbing and average speed)?

(•) Yes
( ) No

Some buses are more reliable than others. Would you object to a bus that is less reliable (on-road breakdown or roadcalls)?

(•) Yes
( ) No

Some buses require more service than others. Would you object to a bus that is less serviceable (Preventative maintenance to prevent roadcalls)?

(•) Yes
( ) No

Some buses are more comfortable than others. Would you object to a bus that is less comfortable (user attention to accessories - i.e. air-conditioning, automatic door, etc.)?

(•) Yes
( ) No

OK

Restart

Back

Exsys

Recommendations

For a bus fleet which intends to to expand the fleet, with:

1000000.0 passengers

52.0% federal funds

25.0% state funds

23.0% other funds

101 to 150 active buses

Average bus age of 11 to 15 years

11 to 25% alternative fuel buses

5 to 10% alternative fuel buses of 50 passenger or greater

26 to 50% buses 40 passenger or greater

Compressed Natural Gas Bus System: Score 76.0

Description of compressed natural gas bus system

Ultra Low Sulfur Diesel Bus System: Score 76.0

Description of ultra low sulfur diesel bus system

Hybrid Diesel-Electric Bus System: Score 79.0

Description of hybrid diesel-electric bus system

Biodiesel Bus System: Score 126.0

Description of biodiesel bus system

Appendix C

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An Interactive Expert System Based Decision Making Model for the Management of Transit System Alternate Fuel Vehicle Assets

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