

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

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Abstract

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 (life-cycle cost, fuel efficiency, vehicle reliability, environmental effects, etc.) that contribute to a more comprehensive approach. This study investigates 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 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. A computer-based prototype system is developed 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 users 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.

Keywords

Expert System Framework, Alternative Fuel Bus, Decision Making Process,

1. Introduction

Energy is an important commodity in the 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). The domestic and global society has become very energy dependent. In this sense, energy is the life blood which fuels the economies and the very progression of the society. This constant need for an ever-increasing energy availability has caused most societies to reimagine their energy strategies for the future. In the U.S., the foreign percentage of the 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 with known and unknown genotoxic compounds to the atmosphere [1] [2] [3].

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:

1.1. APTA Public Transportation Vehicle Database

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 sec-

tion 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.

1.2. APTA Passenger Characteristics Report

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.

1.3. Center for Neighborhood Technology Report

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.

1.4. Argonne Report

The Argonne report [4] 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.

In the work by Shahpar [5], 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 study 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 ExsysCorvid® software platform. 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 me-

thods 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.

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 [6].

Although these studies provided good background information and support for the overarching conceptual assertions under investigation in this study, the integration of expert system technology to enhance the analysis within the work and to inform the understanding of other independent reports and studies provides tangible benefit to the governmental transit community. 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.

The objective of this study is to develop an analytical framework and 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 and eventually translates these insights into a sound investment decision making strategy. This prototype 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 (**Figure 1**).

This paper is organized as follows. Section 2 provides a perspective on the notion of uncertainty in decision-making processes. Section 3 presents work of on uncertainty in fuel availability. Section 4 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. Section 5 presents the analysis of studies on improvements in methods of analysis to enable better design and decision making. Section 6 describes an approach to develop a prototype decision-making system. Section 7 details the creation of the

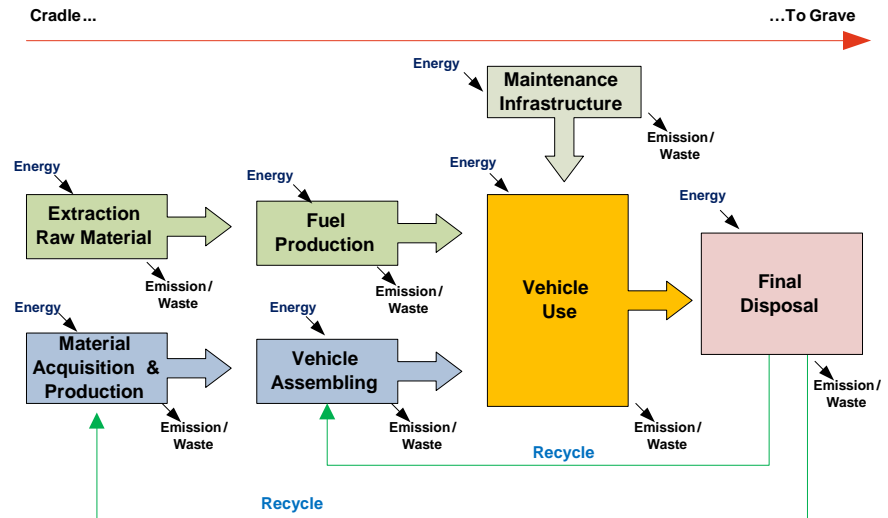


Figure 1. Flow diagram: Cradle to grave LCA overview.

variables and logic in the KBES. Section 8 summarizes the merits and demerits of the KBES and provides suggestions for further research.

2. Uncertainty in Decision-Making

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 [7] [8] [9]. 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:

- 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.

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 [10] [11] [12] [13]. 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 [6].

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 [6]. 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 rules (policies) can be greatly influenced by public sentiment and/or perception [14]. 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 [15]. A cost benefit analysis is widely taken into account to estimate numerical results close to reality and evaluate the environmental impacts and benefits of various schemes and scenarios for broadening and deepening the LCA approaches [16] [17] [18]. The work of Roche *et al.* [19] 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. It is critical to cite the interdependence between the actor, technology and rule factors within this Socio-Technical System. Further, this is a dynamic system 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.

3. Uncertainty in Fuel Availability

3.1. Fuel Use and CO₂ Emissions under Uncertainty from Light-Duty Vehicles in the U.S. to 2050

This section will present the uncertainty associated with fuel availability by investigating the work of [20]; where a stochastic transport emissions policy (STEP) model is presented to quantify the uncertainties in the future fleet fuel use and Green House Gas emissions. The study [20] suggested 22% of the CO₂ 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 CO₂ 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 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:

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

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 530×10^9 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 1260×10^6 Mt of CO₂ 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.

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

The study [20] provides an analysis the CO₂ 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, there are many similarities between this study and the research contained in this study. 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 tran-

sit 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 [6]. 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.

4. Uncertainty in US Fuel Pricing

According to the report [21], on an energy-equivalent basis, CNG is about \$0.19 per GGE (gasoline gallon equivalent) less than gasoline. On a per-gallon basis, E85 is about \$0.09 less than gasoline, and propane is about \$0.62 higher than gasoline, but \$0.14 lower than diesel. B20 prices are higher than regular diesel by about \$0.12 per gallon, while B99/B100 blends have a cost of about \$0.96 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. Such efforts are especially consequential as worldwide consumption trends put increasing pressure on traditional energy sources [22]. 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.

It is critical to mention at this point that volatility and uncertainty not interchangeable. Uncertainty can and does exist 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 deci-

sions, 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.

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

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 [23] and [24]. The proposed improvement anticipated in the policy arena depends upon slight improvements in the capabilities of program managers and policy staffs to translate the 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.

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

The work of [23] 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 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.

5.2. Methodology for a LCA Framework

The study (McKenzie *et al.* 2012) presented a methodological LCA framework where two parameters; cost and 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 [25].

The basic structure of the LCA methodology in this study was derived from the work of [26]. In this work, there was a comprehensive study of LCAs for fuel and propulsion systems. 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 [23] 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.

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

Alternate fuels can address environmental concerns because, in general, tailpipe emissions with these fuels are less than standard diesel fuel [23]. 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.

The proposed improvement 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.

6. Prototype Decision-Making System

6.1. Prototype Based System

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.

The focus of the research for this study 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 an easy to understand user applicable format.

This prototype 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.

6.2. 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:

- There is a correlation between the bus purchasing history/volume and the bus useful life (approximately 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 2013 dollar terms) for the 12 year life, and all data are presented as 2013 dollars.
- 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 [27]. 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 2** shows the structure and relation of defined goals and criteria.

In **Table 1**, 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 is referred to as the Impact Index (Y) for a given alternate fuel technology.

This impact index (Y) number forms the basis for the weighting paradigm for the ExsysCorvid® based decision-making system. A technology with a lower impact index (Y) number for a given criteria is more desirable. Specifically, the

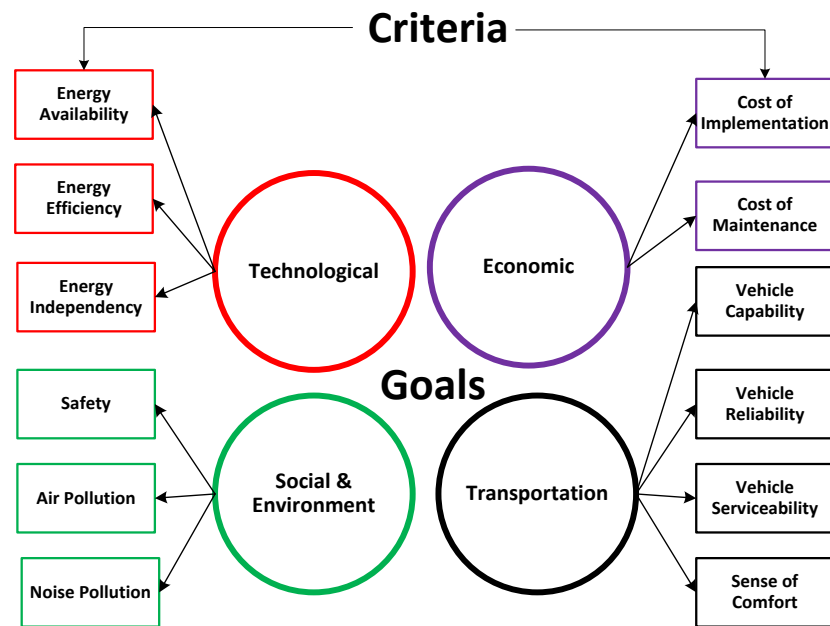


Figure 2. Structure and relation of defined goals and criteria.

Table 1. The ranks of the criterion multiplied by the relative importance of the alternatives with respect to each criterion.

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

lower the (Y), the better that technology is perceived to perform in these criteria as reported by the experts survey respondents.

7. ExsysCorvid Based Prototype Decision-Making Tool

7.1. Prototype Decision-Making Tool

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.

In the creation of the KBES to determine intersection countermeasures, many variables were created. These variables were designed to ask the user questions to gain the necessary information about the intersection to make recommendations for countermeasures to improve safety at the intersection. Depending upon the types of information sought, static list variables or numeric variables were used (Table 2).

The rules in a system are 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.

A complex system may have many rules. Corvid uses Logic and Action Blocks to organize and structure the rules. 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”.

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. 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 (Figure 3). The inputs (answers) provided at the user interface are processed by the inference engine in the ExsysCorvid platform as illustrated in Figure 4.

7.2. Test and Evaluation ExsysCorvid® 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 [28]. 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 were 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.

Figure 5 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.

Table 2. Categories and variables for the knowledge based expert system.

	Categories and variables	Important elements
Static list variables	Alternative_Bus	Ask the user about your overall Fleet Infrastructure.
	Air_Pollution	Some buses produce more air pollution than others. Would you object to a bus that is less environmentally clean (contribute to air pollution)?
	Capability	Some buses are more capable than others. Would you object to a bus that is less capable (cruising distance, slope climbing and average speed)?
	Comfort	Some buses are more comfortable than others. Would you object to a bus that is less comfortable (user attention to accessories- <i>i.e.</i> air-conditioning, automatic door, etc.)?
	Maintenance	Some buses are more costly to maintain than others. Would you object to a bus that is more costly to maintain?
	Noise	Some buses produce more noise than others. Would you object to a bus that is less quiet?
	NRG_Available	Some organizations have more energy availability than others. Would you say your organization's energy availability (supply, storage and cost of storage) is?
	Safety	Some buses provide better safety than others. Would you object to a bus that is less safe (fuel handling properties compared to conventional diesel)?
	NRG_Efficient	Some buses are more energy efficient than others. Would you object to a bus that is less energy efficient?
	NRG_Independence	Some organizations have more energy independence than others. Would you say your organization's energy independence (resilience to pricing fluctuations) is?
	NRG_Infrastructure	Some buses require more capital infrastructure than others. Would you object to a bus that requires more capital infrastructure (refueling stations and depot modification)?
	Purpose	This potential bus purpose is intended.
	Reliability	Some buses are more reliable than others. Would you object to a bus that is less reliable (on-road breakdown or roadcalls)?
	Maintenance	I need to know about your overall Fleet Economic Needs.
	Numeric variables	Serviceability
State_Funds		Of your overall funding, what percentage of state funds is?
Active_Bus		What is the total number of active buses in your fleet?
Bus_Age		What is the average age of buses in your fleet?
Alternative_Bus		What percentage of your buses that are 50 passengers or greater are alternative fuel buses?
Alternative_Fuel		What is the current percentage of alternative fuel buses in your fleet?
Bus_Size		What percentage of your buses are 40 passenger or greater?
Other		Other Funds
Price		What is the current price of gasoline per gallon?
Ridership		What is the average ridership of buses in your fleet?
Confidence Variables	BD	Recommendation score for biodiesel bus system
	CNG	Recommendation score for compressed natural gas bus system
	HDE	Recommendation score for hybrid diesel-electric bus system
	ULSD	Recommendation score for ultra low sulfur diesel bus system

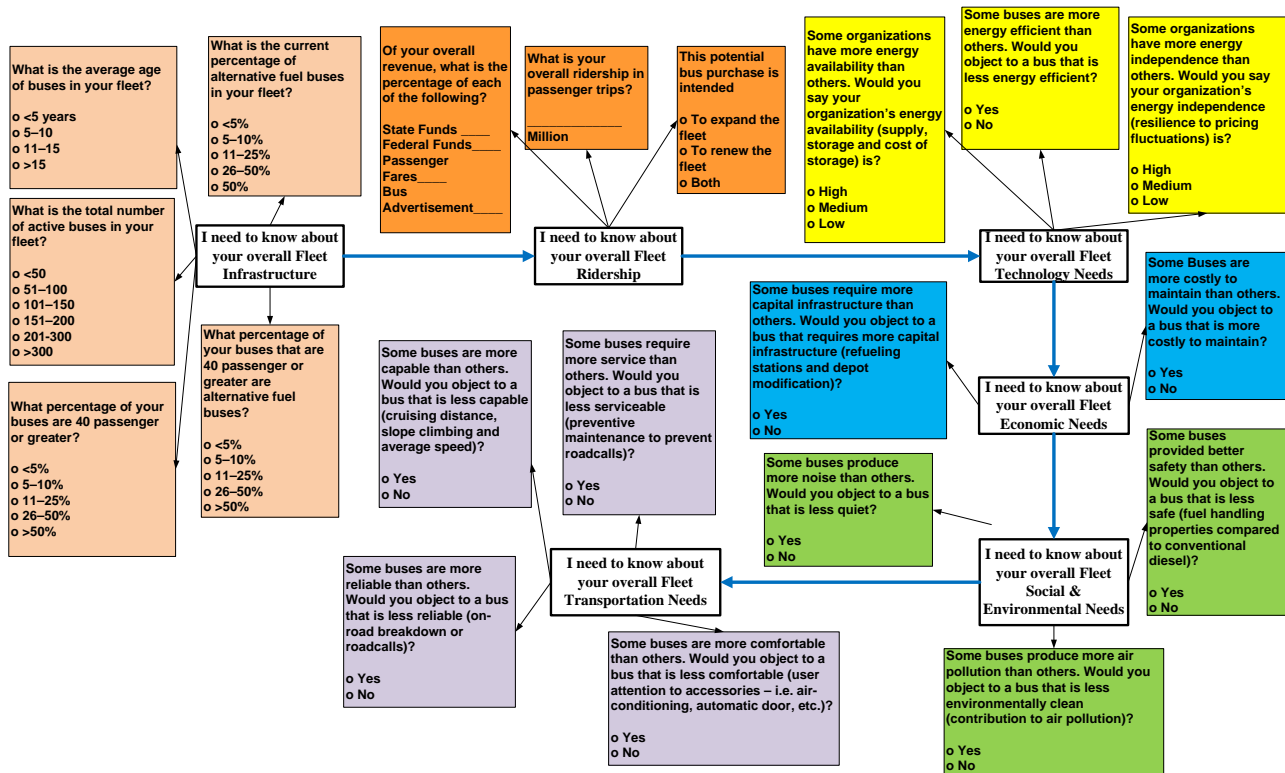


Figure 3. Questions related to the fleet characteristics and criteria.

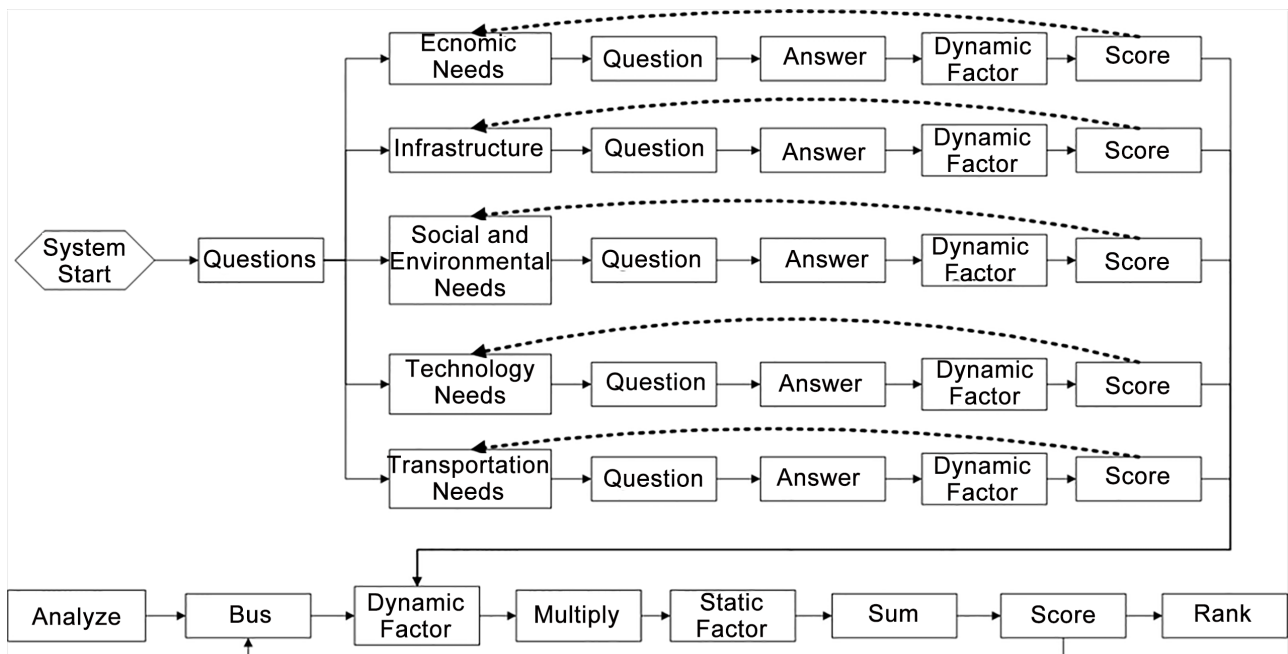


Figure 4. Flow Diagram: Exsys Corvid® based prototype decision-making tool for the management of transit system alternate fuel infrastructures.

8. Summary, Conclusion and Recommendations

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

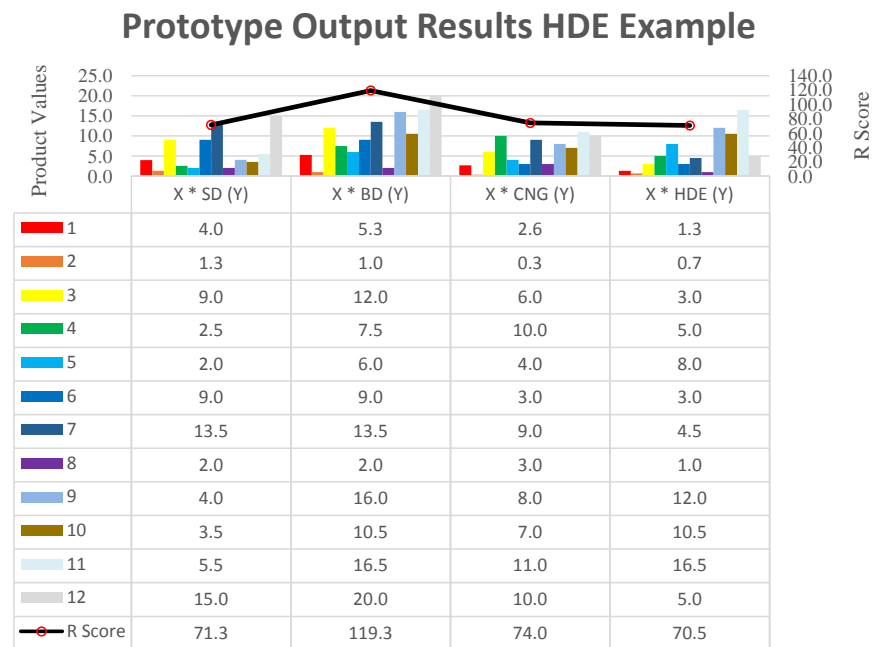


Figure 5. Prototype product and output results (R Score).

robust and sustainable in a dynamic and technologically rich environment. 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. This investigation includes transit system industry review, industry expert survey instrument creation, expert data extraction and analysis, expert system development and other related factors. 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. The notion of uncertainty in decision-making processes was presented 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 ExsysCorvidsystem. It is suggested that future work in the design of a more robust prototype includes a feature which allows user input of these and other uncertainty variables.

This study includes other types of alternate fuel vehicles where the uncertainty in the total fuel use and life-cycle GHG emissions from U.S. light-duty vehicles is quantified, as well as, the major factors which contribute to fuel use and emissions are identified and ranked. Much could be learned about the alternate fuel bus fleet scenario by studying and modeling other more mature fleet alternate fuel applications.

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.

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References

- [1] Laghaei, J., Faghri, A. and Li, M. (2015) Impacts of Home Shopping on Vehicle Operations and Greenhouse Gas Emissions: Multi-Year Regional Study. *International Journal of Sustainable Development & World Ecology*, **23**, 381-391. <https://doi.org/10.1080/13504509.2015.1124471>
- [2] Wahed, M., Faghri, A. and Li, M. (2017) An Innovative Simulation Model for the Operations of a Multipurpose Seaport: A Case Study from Port of Wilmington, USA. *International Journal of Simulation and Process Modelling*.
- [3] Fan, R.M., Zhu, B.-Z., Huang, C.-P., Sheng, Z.-G., Mao, L. and Li, M.-X. (2016) Different Modes of Synergistic Toxicities between Metam/Copper (II) and Metam/Zinc (II) in HepG2 Cells: Apoptosis vs. Necrosis. *Environmental Toxicology*, **31**, 1964-1973. <https://doi.org/10.1002/tox.22197>
- [4] Werpy, M.R., Burnham, A., Mintz, M. and Santini, D.J. (2010) Natural Gas Vehicles: Status, Barriers and Opportunities. Alexandria, VA, ANL/ESD/10-4. <https://doi.org/10.2172/1000207>
- [5] Shahpar, A. (2010) Life-Cycle Cost and Emissions Assessment of Alternative Fuel Buses: A Case Study of the Delaware Authority for Regional Transit (DART). Newark, DE.
- [6] Patil, A., Herder, P. and Brown, K. (2010) Investment Decision Making for Alternative Fuel Public Transport Buses: The Case of Brisbane Transport. *Journal of Public Transportation*, **13**, 115-133. <https://doi.org/10.5038/2375-0901.13.2.6>
- [7] Camerer, C. and Weber, M. (1992) Recent Developments in Modeling Preferences: Uncertainty and Ambiguity. *Journal of Risk and Uncertainty*, **5**, 325-370. <https://doi.org/10.1007/BF00122575>
- [8] Busenitz, L.W. and Barney, J.B. (1997) Differences between Entrepreneurs and Managers in Large Organizations: Biases and Heuristics in Strategic Decision-Making. *Journal of Business Venturing*, **12**, 9-30. [https://doi.org/10.1016/S0883-9026\(96\)00003-1](https://doi.org/10.1016/S0883-9026(96)00003-1)
- [9] Reckhow, K.H. (1994) Importance of Scientific Uncertainty in Decision Making. *Environmental Management*, **18**, 161-166. <https://doi.org/10.1007/BF02393758>
- [10] Ryan, F. and Caulfield, B. (2010) Examining the Benefits of Using Bio-CNG in Urban Bus Operations. *Transportation Research Part D: Transport and Environment*,

- 15, 362-365. <https://doi.org/10.1016/j.trd.2010.04.002>
- [11] Zhang, L., Xu, W. and Li, M. (2009) Co-Evolution of Transportation and Land Use: Modeling Historical Dependencies in Land Use and Transportation Decision-Making.
- [12] Taromi, R., DuRoss, M., Chen, B.T., Faghri, A., Li, M.X. and DeLiberty, T. (2015) A Multiobjective Land Development Optimization Model: The Case of New Castle County, Delaware. *Transportation Planning and Technology*, **38**, 277-304. <https://doi.org/10.1080/03081060.2014.997450>
- [13] Scott, M., et al. (2017) Research of Viable Attributes and Potential to Integrate Curbside Intercity Buses. *Transportation Research Board 96th Annual Meeting*, No. 17-06609, Washington DC.
- [14] Wigan, M.R. (1994) The Realizability of the Potential Benefits of Intelligent Vehicle-Highway Systems: The Influence of Public Acceptance. *Information Technology & People*, **7**, 48-62. <https://doi.org/10.1108/09593849410076816>
- [15] Hutchins, M.J. and Sutherland, J.W. (2008) An Exploration of Measures of Social Sustainability and Their Application to Supply Chain Decisions. *Journal of Cleaner Production*, **16**, 1688-1698. <https://doi.org/10.1016/j.jclepro.2008.06.001>
- [16] Li, M. and Faghri, A. (2014) Cost-Benefit Analysis of Added Cycling Facilities. *Transportation Research Record: Journal of the Transportation Research Board*, **2468**, 55-63.
- [17] Ozden, A., Faghri, A., Li, M. and Tabrizi, K. (2016) Evaluation of Synthetic Aperture Radar Satellite Remote Sensing for Pavement and Infrastructure Monitoring. *Procedia Engineering*, **145**, 752-759. <https://doi.org/10.1016/j.proeng.2016.04.098>
- [18] Li, M., Faghri, A., Ozden, A. and Yue, Y. (2017) Economic Feasibility Study for Pavement Monitoring Using Synthetic Aperture Radar Satellite Remote Sensing: A Cost-Benefit Analysis. *Transportation Research Record (TRR)-Journal of Transportation Research Board*, No. 2645.
- [19] Roche, M.Y., Mourato, S., Fishedick, M., Pietzner, K. and Viebahn, P. (2010) Public Attitudes towards and Demand for Hydrogen and Fuel Cell Vehicles: A Review of the Evidence and Methodological Implications. *Energy Policy*, **38**, 5301-5310. <https://doi.org/10.1016/j.enpol.2009.03.029>
- [20] Bastani, P., Heywood, J.B. and Hope, C. (2012) Fuel Use and CO₂ Emissions under Uncertainty from Light-Duty Vehicles in the US to 2050. *Journal of Energy Resources Technology*, **134**, Article ID: 042202.
- [21] USDOE (2015) Clean Cities Alternative Fuel Price Report. Washington DC.
- [22] Suplee, C. (2008) What You Need to Know about Energy. National Academies Press, Washington DC.
- [23] McKenzie, E.C. and Durango-Cohen, P.L. (2012) Environmental Life-Cycle Assessment of Transit Buses with Alternative Fuel Technology. *Transportation Research Part D: Transport and Environment*, **17**, 39-47. <https://doi.org/10.1016/j.trd.2011.09.008>
- [24] Haller, M., Welch, E., Lin, J. and Fulla, S. (2007) Economic Costs and Environmental Impacts of Alternative Fuel Vehicle Fleets in Local Government: An Interim Assessment of a Voluntary Ten-Year Fleet Conversion Plan. *Transportation Research Part D: Transport and Environment*, **12**, 219-230. <https://doi.org/10.1016/j.trd.2007.02.001>
- [25] Unnasch, S., Pont, J., Chan, M. and Waterland, L. (2007) Full Fuel Cycle Assessment Well to Wheels Energy Inputs, Emissions, and Water Impacts. Sacramento.
- [26] MacLean, H.L. and Lave, L.B. (2003) Evaluating Automobile Fuel/Propulsion Sys-

tem Technologies. *Progress in Energy and Combustion Science*, **29**, 1-69.

[https://doi.org/10.1016/S0360-1285\(02\)00032-1](https://doi.org/10.1016/S0360-1285(02)00032-1)

- [27] Ozden, A., Faghri, A. and Li, M. (2016) Using Knowledge-Automation Expert Systems to Enhance the Use and Understanding of Traffic Monitoring Data in State DOTs. *Procedia Engineering*, **145**, 980-986.
<https://doi.org/10.1016/j.proeng.2016.04.127>
- [28] Frey, R., Faghri, A. and Li, M. (2014) Development of an Expert System for Effective Countermeasure Identification at Rural Unsignalized Intersections. *Transportation Research Board 93rd Annual Meeting*, Washington DC.



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