Expert Systems with Applications 42 (2015) 2835–2848

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Multi-criteria evaluation of alternative-fuel vehicles via a hierarchical hesitant fuzzy linguistic model

Mesut Yavuz [a,*], Basar Oztaysi [b], Sezi Cevik Onar [b], Cengiz Kahraman [b]

[a] *Department of Information Systems, Statistics and Management Science, Culverhouse College of Commerce, University of Alabama, Tuscaloosa, AL, USA*
[b] *Department of Industrial Engineering, Faculty of Management, Istanbul Technical University, Istanbul, Turkey*

ARTICLE INFO

Article history:
Available online 20 November 2014

Keywords:
Alternative-fuel vehicles
Multi-criteria decision making
Hierarchy
Hesitant fuzzy sets
Linguistic terms

ABSTRACT

Decision on alternative-fuel vehicles is one of the most important problems for fleet operations. In this paper we propose a hierarchical hesitant fuzzy linguistic model that captures hesitant linguistic evaluations of multiple experts on multiple criteria for alternative-fuel vehicles. We apply the proposed model on the alternative-fuel vehicle selection problem of a home health care service provider in the USA. The results show that an electric vehicle is the best fit for the application in today's conditions. We also show robustness of the decision through a sensitivity analysis as well as analyze three scenarios representing possible changes in conditions.

1. Introduction

Alternative-fuel vehicles (AFVs) offer (per mile) cost and greenhouse gas (GHG) emission savings, and, hence, they make a viable option for buyers in the market. Despite their potential benefits, AFVs' market penetration is still limited, due to some cost and non-cost factors.

If a vehicle selection decision is considered solely from a cost perspective, it can be formulated as a relatively simple, single-objective optimization problem. The problem then can be solved using the vast engineering economy literature, which offers a variety of mathematical models to compare decision alternatives based on their initial purchase, operating and maintenance costs. An AFV is an advanced technology product compared to the traditional gasoline or diesel vehicles (GDVs), and as expected from an advanced technology product, is typically more expensive to purchase, but has lower operating and maintenance costs. In initial stages of their market penetration, government subsidies are an important driving force bringing AFV initial purchase costs down to levels competitive with those of GDVs (Struben & Sterman, 2008). With further technological development, AFVs could become economically preferable even without subsidies.

Non-cost factors in vehicle selection largely vary in their causes and severity. Golob and Gould (1998) find that even though most household vehicles travel less than 50 miles per day, drivers still wanted to have a driving range of 100 miles, and also that having an electric vehicle in a household would mean shifting some of the driving load to other vehicles in the household. A more recent study by Stephens (2013) shows limited driving range, limited fueling and charging stations, and long fueling and charging times to be the most important non-cost barriers to AFV consumer adoption. Yavuz and Capar (2014) focus on adding an AFV to an existing fleet of GDVs and investigate the considered AFV adoption's impact on fleet operations via optimization modeling. The authors show that, for a service fleet operation, driving range and refueling and charging station availability are very important whereas refueling or recharging time does not have as big an impact on overall fleet performance.

Other non-cost barriers in Stephens's (2013) study, in order of importance, are (i) unfamiliarity, benefit uncertainty, and lack of awareness or information, (ii) perceived dispositions against advanced technology vehicles, (iii) lack of adequate technology standardization, (iv) limited availability and diversity of vehicle makes and models, and (v) regulations. In a related study Browne, O'Mahony, and Caulfield (2012) classify non-cost barriers into (i) technical or commercial, (ii) institutional and administrative, (iii) public acceptability, (iv) legal or regulatory, (v) policy failures and unintended outcomes and (vi) physical barriers. Some of these non-cost barriers can be overcome with policy resolutions, while some others require a change in the public perception of AFVs, which may take much longer to happen on its own.

Commercial fleets present a great opportunity to increase AFV market penetration and visibility, and thereby to speed their technological development as well as to improve public perception.

---

* Corresponding author.
E-mail addresses: myavuz@cba.ua.edu (M. Yavuz), oztaysib@itu.edu.tr (B. Oztaysi), cevikse@itu.edu.tr (S. Cevik Onar), kahramanc@itu.edu.tr (C. Kahraman).

http://dx.doi.org/10.1016/j.eswa.2014.11.010
0957-4174/

Therefore, there is more potential return from focusing optimization efforts on fleet operations in the early adoption stages of AFVs.

A significant advantage of fleet operations is that a commercial fleet may have its own filling station. If a decision is made to adopt an alternative-fuel technology for all vehicles in the fleet, investment costs may be well justified to open a dedicated filling station so that all fleet vehicles are refilled overnight and start each day with a full tank or depot. Table 1 presents numbers of filling stations of each fuel type in the continental U.S., with data obtained from Alternative Fuels Data Center (2014). While some fuel types have large numbers of filling stations, they fade in comparison to gasoline filling stations (roughly 150,000 in the continental U.S.)

As seen in Table 1, a majority of biodiesel and about half of natural gas filling stations in the continental U.S. are private, exclusively serving the owner's fleet.

Fleet operations vary largely in their nature and the characteristics of vehicles they require. Table 2 presents a summary of six fleet operations.

The fleet operations addressed here are selected to demonstrate different operating characteristics. The list is not meant to be exhaustive by any means. Taxicabs are driven almost non-stop in urban environments. They drive a large number of miles every day and when they need to refuel, they need convenient and quick refueling. Technical service providers pay scheduled visits to a set of customers at their locations every day and they spend significant time with customers. Consider a home health care provider that visits 5 patients on average every day for 1-h visits. (S)he does not need a large vehicle as (s)he does not have heavy or bulky equipment to carry to patients' homes. School buses have predetermined routes that they drive during specified times of the day. Last mile delivery vehicles drive different routes every day, optimized to meet that day's demand. Those delivery vehicles carry typically small packages to a large number of customers, thus they are typically large vans or small-to-medium size trucks. Cargo transport in the short distance usually requires medium size trucks, whereas long distance transport requires large trucks.

Fuel characteristics and evaluation criteria are location-dependent to a large extent. Furthermore, evaluation criteria incorporate subjective judgments into the decision-making process. Fuzzy decision-making genuinely fits such subjective and uncertain decision-making environments (Behret, Öztaysi & Kahraman, 2012; Cevik & Ates, 2008). In this study we develop a fuzzy multi-criteria decision-making framework for vehicle selection and discuss its application in a select fleet operation. The developed algorithm is a generalized version of Rodríguez, Martínez, and Herrera (2013) hesitant fuzzy linguistic term sets (HFLTS) based evaluation, which considers only one criterion. HFLTS has been successfully applied to various problems in the literature and cited in many publications: Investment problem (Zhang & Wu, 2014), warfare capability assessment (Wang, Wang, Chen, Zhang & Chen, 2014), movie recommender system (Liao, Xu & Zeng, 2014), evaluating university faculty for tenure and promotion (Meng, Chen & Zhang, 2014), assessing engines (Meng, Chen & Zhang, 2014), supplier selection (Liu & Rodríguez, 2014). In this paper we extend HFLTS to multi-criteria evaluation, which not only fits the application considered in this study but could be used in many other expert system applications. The main difference of our paper is that it uses a hierarchical multi criteria decision making approach utilizing HFLTS and thus it can handle complex problems, such as alternative-fuel vehicle selection, by dividing them into sub-problems.

The remainder of the paper is organized as follows. Sections 2 and 3 jointly describe the alternative-fuel vehicle selection decision problem studied in the paper. Section 2 briefly introduces alternative-fuel vehicles, their main advantages and shortcomings. Section 3 presents the criteria used in alternative-fuel vehicle selection and organizes them into a hierarchy. Sections 4 and 5 present the multi-criteria decision-making method proposed in this paper for the studied alternative-fuel vehicle selection problem. Section 4 reviews related work on hesitant fuzzy linguistic term sets (HFLTS). Section 5 presents the proposed multi-criteria HFLTS method. Section 6 implements the proposed decision-making method on a technical service vehicle fleet based in Winchester, Virginia, USA. In this section sensitivity and scenario analyses are also given. Finally, Section 7 concludes the paper by discussing key findings and pointing at possible future research directions.

Table 1
Alternative-fuel stations in the continental U.S.

Fuel type	Total	Public	Private
Biodiesel	815	324 (40%)	491 (60%)
CNG	1,334	672 (50%)	662 (50%)
Electric	9,153	7,627 (83%)	1,526 (17%)
Ethanol	2,668	2,383 (89%)	285 (11%)
Hydrogen	55	10 (18%)	45 (82%)
LNG	90	49 (54%)	41 (46%)
LPG	2,989	2,738 (92%)	251 (8%)
Total	17,104	13,803 (81%)	3,301 (19%)

Table 2
Fleet operations.

Fleet operation	Main characteristics
Taxicabs	Cities and suburbs, continuous driving
Technical service	Few scheduled customer visits, lengthy stays at customer sites
School buses	Cities and suburbs, predetermined routes
Last-mile delivery	Package delivery, daily routes, continuous driving
Full-truckload short-distance cargo transport	Same-day delivery from production plants to customers or ports
Long-distance cargo transport	Multi-day trips

2. Alternative-fuel vehicles

Gasoline and diesel are the two traditional fuel types. Both of them are obtained from petroleum, therefore are fossil fuels. Gasoline is the most common fuel used in internal combustion engines, and gasoline filling stations are the most widely available worldwide. Diesel fuel has higher energy density per volume than gasoline. Therefore, diesel vehicles report higher miles-per-gallon fuel efficiencies than their gasoline equivalents. In terms of CO_2 emissions, gasoline and diesel are about the same. In terms of vehicle performance, gasoline is a better fit for applications that need agility and higher speeds. In an analogy a gasoline vehicle is like a racehorse, whereas a diesel vehicle is more like a workhorse.

An AFV is typically very broadly defined as a vehicle that runs on a fuel other than "traditional" petroleum fuels. This definition includes any engine technology that does not run solely on petroleum. Per this broad definition; flexible fuel, dual fuel and hybrid electric vehicles are all considered AFVs. While those technologies use petroleum as a secondary resource, and, hence help to reduce petroleum consumption, their evaluation is subject to driving characteristics. For example, a hybrid electric vehicle with 20 miles of all-electric driving range can hardly be considered an electric vehicle if it is driven 200 miles a day with no intraday recharging. For sake of clarity, in this paper, we define an AFV as a vehicle that runs solely on a non-traditional, alternative fuel. At the conceptual level, we consider the six alternative-fuel types shown in Table 3.