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Multi-criteria alternative-fuel technology selection using interval-valued intuitionistic fuzzy sets

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ABSTRACT

Fleet operators periodically update and upgrade their vehicles in order to take opportunity of new technologies. Alternative-fuel vehicles provide opportunities to lower fuel costs as well as to reduce environmental footprint. Decision on alternative-fuel vehicle adoption is a challenging problem for fleet operators in today's technological and market development level. This paper focuses on the alternative-fuel technology selection problem of a utility company in the USA. The paper develops a multi-expert, multi-criteria decision making (MCDM) method based on interval-valued intuitionistic fuzzy sets (IVIFS) with linguistic data, and finds that the best fit for the utility company is an extended-range natural gas vehicle.

1. Introduction

The transportation sector is the biggest consumer of petroleum in the U.S. as well as worldwide (EIA, 2016a, 2016b). Conventional vehicles use gasoline or diesel fuel, which are obtained from petroleum. In recent years – due to reasons such as high CO_2 emissions, oil price fluctuations, feared petroleum shortages in the near future and increased dependency on imported oil – we have witnessed increased interest in alternative-fuel technologies both on the consumer and the automotive manufacturer side. These technologies use fuels other than petroleum (in gasoline or diesel form), and include biodiesel, compressed natural gas (CNG), electric, ethanol, hydrogen, liquefied natural gas (LNG), and liquefied petroleum gas (LPG). Today, there are a variety of alternative-fuel vehicles (AFVs) available in different vehicle classes for a broad range of applications.

Commercial fleets are critical for advancement of AFVs. Fleet operators may decide to purchase multiple vehicles at a time. Investing in a filling station may also be economical for a fleet, much more so than for a person. They are also more sensitive to reduction of per-mile fuel costs and CO_2 emissions, both of which are achieved at the same time by some AFVs today. Even when CO_2 emission reduction comes at a monetary cost, fleets owned by governments or leading corporations may decide to accept a cost increase to reduce CO_2 emissions, as a way to demonstrate their commitment to environmental sustainability. For example, van Rijnsoever et al. (2013) show local governments are willing to pay 25–50% more for alternative-fuel vehicles with the same utility. Table 1 presents a breakdown of numbers of fleet and all vehicles by vehicle and fuel type, based on data from U.S. Energy Information Administration (EIA, 2015). For AFVs, percentages in the vehicle class are given in parentheses, and they show slightly higher adoption rates in commercial fleets.

Selection among alternative-fuel technologies is a MCDM problem with many conflicting attributes. Moreover, experts generally prefer making linguistic assessments rather than exact numerical judgements. Such linguistic assessments can

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Table 1
U.S. Fleet and all vehicle numbers breakdown by vehicle and fuel type (2015 data, in millions).

Vehicle & fuel type	Conventional	Alternative-fuel		Total
Commercial fleets				
Car	5.01	0.30	(5.6%)	5.31
Light truck	4.57	0.69	(13.1%)	5.26
Total	*9.58*	*0.99*	*(9.4%)*	*10.57*
All vehicles				
Car	122.12	6.85	(5.3%)	128.97
Light truck	87.48	12.82	(12.8%)	100.30
Total	209.60	19.67	(8.6%)	229.27

be converted to their corresponding numerical values and then be incorporated into a MCDM method through the fuzzy set theory. In the literature, ordinary fuzzy sets have been extensively used in MCDM methods such as fuzzy TOPSIS (Kahraman et al., 2007), fuzzy AHP (Tüysüz and Kahraman, 2006), and fuzzy VIKOR (Kaya and Kahraman, 2011). Extensions of ordinary fuzzy sets such as hesitant fuzzy sets (Torra, 2010), intuitionistic fuzzy sets (Atanassov, 1986), and type-2 fuzzy sets (Zadeh, 1975) have been recently introduced into multi-criteria decision making, and shown to be advantageous in better defining the membership functions than ordinary fuzzy sets (Boran et al., 2009, 2011; Boran, 2011; Cevik Onar et al., 2015; Kahraman et al., 2015).

In this paper, we develop an interval-valued intuitionistic fuzzy (IVIF) MCDM method for AFV selection. The method utilizes intuitionistic fuzzy sets' strength in defining the membership, non-membership and hesitancy for expert assessments.

There are few works on the evaluation of energy technologies using IFS in the literature. Boran et al. (2012) evaluate renewable energy technologies for electricity generation in Turkey using intuitionistic fuzzy TOPSIS. The considered alternatives are photovoltaic, hydro, wind and geothermal energy. Wang and Sun (2012) analyze the risks of energy engineering projects in China's enterprises using AHP and intuitionistic fuzzy sets. Abdullah and Najib (2016) develop an intuitionistic fuzzy analytic hierarchy process (IF-AHP) for selecting the best energy technology in Malaysia. Cevik Onar et al. (2015) evaluate wind energy investments for selecting the appropriate wind energy technology using IVIFS. These sets are utilized in both pairwise comparison matrices and in the calculation of score judgment and possibility degree matrices. Montajabiha (2016) proposes a new PROMETHEE II method for solving multi-criteria alternative-fuel group decision making problems. The weights of all criteria and the ratings of each alternative are represented by IFS. In order to show the applicability of the method, it is applied to sustainable energy planning problems. None of these works address alternative-fuel technology selection.

The remainder of this paper is organized as follows: Section 2 presents a literature review on alternative-fuel technologies. Section 3 includes the preliminaries of IVIFS. Section 4 gives the steps of the proposed decision model. The model is applied to an alternative-fuel technology selection problem in Section 5. Finally, the last section concludes the paper with suggestions for further research.

2. Alternative-fuel vehicles

In this study an alternative-fuel is defined as a transportation energy source other than petroleum. Petroleum, in gasoline or diesel fuel form, has been the primary energy source for transportation for roughly a century. Various alternative-fuels have been tried in years. In fact, electric vehicles were more common than gasoline vehicles in the United States in early 1900s (Burton, 2013). With the advancement of the internal combustion engine, gasoline or diesel vehicles became the most commonly used type and they have enjoyed their lead market position ever since.

Economic (particularly in years when gas prices significantly increase) as well as environmental reasons prompt developers to investigate alternative-fuel technologies. The past few decades have witnessed several attempts with varying degrees of success. Failures are mainly due to lack of information available to decision makers (see von Rosenstiel et al., 2015 for a recent example). While hype and disappointment with alternative-fuels seems to be cyclical (Melton and Axsen, 2015), today there are very viable options available to serve both personal and commercial transportation needs. The number of alternative-fuel and hybrid electric light- and medium-duty vehicles available for purchase in the United States increased from 56 in 2010 to 191 in 2015 (AFDC, 2015a). Similarly, automotive manufacturers continuously develop new AFV models in medium- and heavy-duty vehicle classes. In the following Section 2.1, we focus on six types of alternative fuels and briefly state some of their key characteristics.

2.1. Alternative fuels

2.1.1. Biodiesel

Essentially a renewable diesel fuel, biodiesel is obtained from various biological wastes and crops. Biological wastes (e.g., cooking oil, animal fat, etc.) are produced as byproducts in households and industrial facilities. On the other hand, crops (e.g.,