A Multi-criteria Decision Analysis Model on the Fuels for Public Transport with the Use of Hybrid ROC-ARAS Method

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ABSTRACT

The motivation of this paper is the way in which the alternative fuel modes for public transport are analyzed. The aim is proposing a hybrid method to select the best fuel for public transport. The buses with old and new alternative fuels are considered in this paper. Several types of fuels are considered as alternative-fuel modes, e.g., conventional diesel, ultra-low-sulfur diesel fuel, bio-diesel fuel, and electric and gasoline hybrid engine. Moreover, many decision criteria categorized into performance, environmental, economical, infrastructure, technological, social, and risk are taken into consideration. The paper uses a hybrid multi-criteria decision analysis model to rank the fuel modes and/or choose the most efficient one. This hybrid method consists of rank order centroid method to assign the weights to the criteria, and additive ratio assessment technique to analyze the decision-making matrix. To demonstrate the applicability and flexibility of the model, a case study with data given by the experts from the respected fields is employed. The result presents that the liquefied propane gas (LPG) outperforms the other options in terms of the selected criteria.

1. Introduction

Energy is a basic need for the economic development of any country. The geographical distribution of petroleum resources is changing as reserves are being discovered and accessed using a variety of exploration technologies; nevertheless, this distribution of oil supply mostly does not coincide with where the demand is located. This results in high fuel costs, which primarily depend on crude oil price (Singh et.al, 2018).

While global fossil fuel reserves are diminishing, worldwide energy demand is constantly increasing due to the evolution of energy intensive life-styles. Experts estimate that the global demand for energy could rise by more than 50 percent between 2009 and 2030, and the oil production will reach a peak around 2020–2030. Burning fossil fuels generates carbon dioxide (CO2), a green-house gas, leading to global warming. It is correspondingly necessary to find cleaner fuels, which do not originate from fossil resources. Vehicular pollution cannot be avoided because the pollutants are emitted at the ground level, close to human breathing level. The severity of vehicular pollution is reflected in increased human mortality and morbidity. Vehicular pollution affects human health adversely due to the presence of carbon monoxide (CO), CO2, unburned hydrocarbons (HC), the oxides of nitrogen (NOx), and suspended particulate matter (PM) amongst others in the engine exhaust. Almost all countries are working on the methods for CO2 emission reduction from engine tailpipe to combat this menace (Singh et al., 2018). To resolve these problems, oil company investigators have focused on selecting the alternative fuels, which are affordable, sustainable, and environment-friendly and can fulfil the requirements of public transport.

There are several researches concentrating on comparing and describing the performance of alternative-fuel vehicles.

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To assess the transportation fuels for Singapore, Poh and Ang (1999) used forward and backward analytic hierarchy process (AHP). Winebrake and Creswick (2003) applied AHP to evaluate the future of hydrogen fueling systems for transportation. In their investigation, scenario analysis was utilized to build evaluation mode by both of these teams. The research of Tzeng et al. (2005) along with an empirical example attempted to summarize the most promising developments of alternative-fuel buses suitable for the urban area and to explore their favorable future directions by comparing these alternatives to the characteristics of the conventional bus with an internal combustion diesel engine. To this end, they presented a multi-criteria investigation of these alternative-fuel modes with a set of data provided by different groups of Taiwanese experts representing both engineering bodies and academia. They used the technique for order preference by similarity to ideal solution (TOPSIS) method which is one of the most popular compromise methods for evaluating and ranking different alternatives. The framework developed by Patil et al. (2010) gives an insight into the interactions between the actors, rules, and technology components of the transport sector and highlights the way policies affect technology development and decision-making for public transport buses using alternative fuels. Vahdani et al. (2011) applied two fuzzy decision-making models to alternative-fuel bus selection. They considered several types of fuel modes, i.e. electricity, fuel cell (hydrogen), and methanol. Farkas (2013) considered multi-attribute object measurement (MAROM); his paper was built on the excellent work of Tzeng et al. (2005). Reviewing the relative literature indicates that there is not a comprehensive model including a variety of alternatives and criteria; such a model can offer enough flexibility to the analyst. Moreover, the existent techniques ask the experts to give subjective quantitative weights. Barron and Barrett (1996) stated that various techniques for eliciting exact weights from the experts may suffer several counts because the results are highly dependent on the elicitation method, and there is no agreement as to which method produces more accurate weights. On the other hand, the group of experts may not be able to reach agreement on a set of exact weights. In such situations, it may be realistic to use the objective weights.

This paper aims at proposing an applicable hybrid method to select the best fuel for public transport. The paper tries to consider comprehensive lists of fuel modes and decision criteria. Further, an “approximate weighting method” will be used to prevent the challenges mentioned above. The rest of this paper is organized as follows: Section 2 describes the types of alternative-fuel buses evaluated in the current research; Sections 3 introduces the criteria for analyzing the alternatives; Section 4 introduces the procedure of decision-making through a hybrid methodology, followed by a numerical case in Section 5. Conclusions are drawn in the final section.

2. Overview of alternatives

There are numerous solutions as the fuel/engine technologies for public transport available in the international market. In this paper, we consider 18 alternatives extracted from the works of Sperling (1995), Morita (2003), WSU (2004), Tzeng et al. (2005), Patil et al. (2010), Farkas (2013), Mousaei and Hatefi (2015), and so on. Following, we give a brief discuss on these technologies.

2.1. Conventional Diesel (CD)

The CD engine is an internal combustion engine in which the ignition of the fuel injected into the combustion chamber is caused by the elevated temperature of the air in the cylinder due to mechanical compression. The basic difference between a CD and a gasoline engine is that in a CD, the fuel is sprayed into the combustion chambers through fuel injector nozzles just when the air in each chamber has been so greatly pressurized that it is hot enough to ignite the fuel spontaneously (Sclar, 2011). There have been notable improvements in CD technology over the past years (Gifford, 2003).

2.2. Ultra-Low-sulfur Diesel fuel (ULSD)

Diesel emissions are reduced by advanced engine combustion controls, including turbo-charging, after-cooling, high pressure fuel injection, retarding injection timing, and optimizing combustion chamber design. These advanced technologies are known as “clean diesel” (Patil et al., 2010). ULSD as an available fuel in the market is a type of clean diesel with a lower amount of sulfur. ULSD has been refined so that its sulfur content is 15 parts per million (ppm) or less. This is 97% cleaner than CD, which contains an average of 500 ppm of sulfur. Sulfur, a natural part of the crude oil from which diesel fuel is derived, is one of the key causes of particulates or soot in diesel. Soot is the main culprit of diesel engines noxious black exhaust fumes, and is among the prime contributors to air pollution. Since 2006, almost all of the petroleum-based diesel fuel available in Europe and North America has been of a ULSD type. The move to lower sulfur content allows for the application of advanced emission control technologies that substantially lower the harmful emissions from diesel combustion (Omidvarborna et al., 2014).

2.3. Bio-diesel Fuel (BD)

BD (e.g. soy diesel) refers to a vegetable oil-, or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, ethyl, or propyl) esters. BD is typically made by chemically reacting lipids (e.g. vegetable oil, soybean oil, and animal fat) with an alcohol producing fatty acid esters (Omidvarborna et al., 2014). Biodiesel is meant to be used in standard diesel engines and is thus distinct from the vegetable and waste oils used to fuel converted diesel engines. Biodiesel can be used alone or blended with petro diesel in any proportions; biodiesel blends can also be used as heating oil. The National Biodiesel Board (NBB) also has a technical definition of "biodiesel" as a mono-alkyl ester.

2.4. Compressed Natural Gas (CNG)

Natural gas (NG) is a mixture of hydrocarbons, mainly methane, produced either from gas wells or together with crude oil production. CNG is made by compressing NG to less than 1/100th of its volume at standard atmospheric pressure and temperature. CNG consists mostly of methane and is drawn from gas wells or in conjunction with crude oil production. Two types of CNG fuel systems are on the market: dedicated vehicles, which operate exclusively on NG, and dual-fuel vehicles, which can use both NG and gasoline (Mousaei and Hatefi, 2015).

2.5. Liquefied Propane Gas (LPG)

LPG is a flammable mixture of hydrocarbon gases, mainly propane and butane, used for various heating purposes and as vehicle fuel. LPG is a bi-product from oil refining and NG processing. Even though LPG is a relatively small energy source, over 240 million tons are consumed worldwide each year (The World LPG Association, 2010). In fact, this fuel is regarded as a key medium-term option in the transition to sustainable fuels and transport (Raslavicius et al., 2014). LPG is supplied in a variety of ways including in canisters, cylinders, and in bulk storage tanks.

2.6. Liquefied Natural Gas (LNG)

LNG is produced through the liquefaction process of NG, which can be used to power heavy-duty vehicles such as transit buses (IEA, 2011). LNG is NG (predominantly methane, CH4, with some mixture of ethane C2H6) which has been converted to liquid form for the ease and safety of non-pressurized storage or transport. It takes up about 1/600th the volume of NG in the gaseous state (Uz, 2012). It is odorless, colorless, non-toxic, and non-corrosive. Hazards include flammability after vaporization into a gaseous state, freezing, and asphyxia. The liquefaction process involves the removal of certain components such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty in the downstream. The NG is then condensed into a liquid at close to atmospheric pressure by cooling it to approximately −162 °C; maximum transport pressure is set at around 4 psi. NG is mainly converted into LNG to achieve the NG transport over the seas where laying pipelines is not feasible technically and economically (Ulvestad and Overland, 2012).

2.7. Dimethyl Ether (DME)

DME is a fuel created from NG, coal, or biomass. The cetane number of DME is so high that it can be used in diesel engines (Semelsberger et al., 2006). Because DME is a gas at room temperature, it must be pressurized in large tanks for transportation and storage. In the future, DME can be an alternative to conventional diesel fuel. DME resembles LPG in many ways and is as easy to handle as LPG; its calorific value per kilogram is close to coal, better than methanol, much better than hydrogen, and less than LPG, diesel, or methane.

2.8. Gas-To-Liquid (GTL)

GTL technology converts NG into high-quality liquid petroleum products including diesel, naphtha, methanol, DME, and others; GTL fuel (i.e. GTL diesel) is produced through GTL technology. GTL processes with Fischer-Tropsch (FT) technology first convert NG to synthesis gas, which is a mixture of carbon monoxide and hydrogen, and it then converts this synthesis gas into mainly long-chain paraffin hydrocarbons and distillates, which are cracked into conventional transportation fuels. The process has a high distillate yield and produces a lighter fraction, which can be used as a gasoline blending component or as a feedstock for chemicals production. The energy efficiency of the process in converting NG to liquid products is 58-65% (NPC, 2012).

2.9. Hythane (HCNG)

CNG has a low laminar burning velocity, which makes it more prone towards knocking. On the other hand, hydrogen has a high laminar burning velocity, which makes it a better supplement to CNG. Thus, the blend obtained by mixing hydrogen and CNG known as hythane or HCNG has the advantages of both parent fuels, which make it a promising fuel for automobiles (Yadav et al., 2017). Hence, in an effort to reduce the pollutants of CNG buses further, they can be converted to run on hythane (Bauer and Forest, 2001). HCNG is a mixture of 20% by volume of H2 and 80% methane (Hythane, 2007).

2.10. Hydrogen Fuel Cell (H2FC)

An H2FC (so-called fuel cell battery) is an electrochemical cell that converts the chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent. Fuel cells are different from batteries in requiring a continuous source of fuel and oxygen (usually from air) to sustain the chemical reaction, whereas in a battery the chemical energy comes from chemicals already present in the battery. Fuel cells can produce electricity continuously for as long as fuel and oxygen are supplied. Daimler–Benz Company has already developed a prototype vehicle with a fuel cell. H2FC buses are being evaluated from many different perspectives; the life cycle assessments of H2FC buses show that green H2 is a key for significant environmental benefits compared with fossil-driven diesel buses (Lozanovski et al., 2018).

2.11. Methanol and Gasoline Blend (MG)

The MG is a combination of 85% methanol (M85) and 15% gasoline. Brinkman et al. (1975) measured the octane number of methanol–gasoline blends and found out that the research and motor octane numbers increased with increasing methanol amount in the fuel blend. The vehicle that can use a fuel with different combinations of methanol and gasoline is called flexible fuel vehicle (FFV). The FFV engine can run smoothly with any combinations of gas with methanol (Tzeng et al., 2005).

2.12. Opportunity Charging (OC)

Heavy vehicle charger (HVC) products offer an ideal solution for OC, ensuring zero-emission public transit during the day without impacting on the normal operation of the route. The source of power for the OC electric vehicle (OCEV) is the combination of a loaded battery and fast OC during the time the bus is idle when stopped. Indeed, when the bus idles at a bus stop, charging coils embedded in the road charge the bus for as long as it remains at the stop (Fisher et al., 2014). During the 10–20 seconds when the bus is stopped, the power reception sensor on the electric bus (installed under the bus) will be lowered to the charging supply plate installed in front of the bus stop to charge the battery. Within 10 seconds of a stop, the battery is charged with 0.15 kWh power (depending on the design of the power supply facility), and the power supplied is adequate for it to move to the next bus stop. This system has allowed electric city buses to reduce their battery sizes, thus making the buses more efficient by reducing their weight. Similar technology could also reduce the size of the heavy batteries carried by electric cars and other vehicles (Fisher et al., 2014).

2.13. Direct Electric Charging Engine (DEC)

A zero-emission alternative to petroleum that has been available for many years is electricity, and is an option currently used in many cities with electric-cable buses. Recent technology, however, uses electricity independently of a fixed electric cable by using fuel cells or battery storage. The big appeal of electricity is having a clean and quiet operating system. Some cities and countries have begun to use electric buses, but their future is unlikely because of the high costs. This type of electric bus is in the prototype design stage. The power for this vehicle comes mainly from the loaded battery. Once the battery power is insufficient, the vehicle will have to return to the plant to conduct recharging. The development of a suitable battery is also critical for this mode of vehicle. If a greater amount of electricity can be stored in the battery, the cruising distance by this vehicle will be longer (Tzeng et al., 2005).

2.14. Exchangeable-battery Electric Engine (EBE)

The objective of an electric bus with an exchangeable battery is to affect a fast battery charge and to achieve a longer cruising distance. The bus is modified to create more on-board battery space, and the number of on-board batteries is adjusted to meet the needs of different routes. The fast exchanging facility has to be ready to conduct a rapid battery exchange so that the vehicle mobility can be maintained (Tzeng et al., 2005; Farkas, 2013).

2.15. Electric and Gasoline Hybrid Engine (E&G)

The electric-gasoline vehicle has an electric motor as its major source of power and a small-sized gasoline engine. When the electric power fails, the gasoline engine can start functioning and continue the trip meanwhile the kinetic energy rendered during the drive will be turned into electric power to increase the vehicle cruising distance (Tzeng et al., 2005; Farkas, 2013).

2.16. Electric and Diesel Hybrid Engine (E&D)

The electric–diesel vehicle has an electric motor and a small-sized diesel engine as its major sources of power. When the electric power fails, the diesel engine can start functioning and continue the trip; meanwhile the kinetic energy rendered during the drive will be turned into electric power to increase the vehicle cruising distance (Tzeng et al., 2005; Farkas, 2013).

2.17. Electric and CNG Hybrid Engine (E&CNG)

The electric-CNG vehicle has an electric motor and a small-sized CNG engine as its major sources of power. When the electric power fails, the CNG engine provides the power, and the kinetic energy produced is converted to electric power to permit a continuous travel (Tzeng et al., 2005; Farkas, 2013).

2.18. lectric and LPG hybrid engine (E&LPG)

Like E&CNG, the electric-LPG vehicle has an electric motor and a small-sized LPG engine as its main sources of power. When the electric source fails, the LPG engine starts providing the needed power (Tzeng et al., 2005; Farkas, 2013).

Now, let us use the literature to list the most important features of the choices. Table 1 presents the summarized results.

3. Overview of Criteria

The evaluation of alternatives can be performed according to different criteria. This paper categorizes the criteria as performance, environmental, economical, infrastructure, technological, social, and risk aspects. For the sake of establishing the list of criteria (see Table 2), the seminal paper of Tzeng et al., (2005) with 11 criteria, and the investigation of Mousaei and Hatefi (2015) with 13 criteria together with some additional resources are considered.

4. The Methodology

The course of action of the proposed methodology, consisting of 4 stages and 11 steps, is as follows:

Stage I: There are 2 steps in this stage: Step 1: the experts select the alternatives to be analyzed among CD, ULSD, BD, CNG, LPG, LNG, DME, GTL, HCNG, H2FC, MG, OC, DEC, EBE, E&G, E&D, E&CNG, and E&LPG. The number of selected alternative fuel modes is m; let$_1$ $A_1,\ldots,A_{(m)}$ denote the alternatives. Step 2: the experts also choose the local criteria among the list of criteria, including ES, EE, FS, VC, AP, SP, WP, NP, IC, MC, DM, TE, SE, CT, WT, PP, RF, IA, TM, SI, IR, SA, SC, PR, ER, and SR. The number of selected criteria is n; let $C_1,\ldots,C_n$ indicate the criteria.

Stage II: The process of solving decision-making problems, similar to the other methods of MCDM, starts with forming the decision-making matrix. Hence, in this step, we establish a decision-making matrix as (1). The score x_{ij}, the element of the decision-matrix, describes the performance of alternative$A_{(i)}$ for criterionC_j. The performance scores are assumed to be numbers between 1 (for the worst case) and 9 (for the best case).

$$\begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \tag{1}$$

Stage III: This stage is related to determining the criteria weights. The weight of criterion$C_{(j)}$ is denoted by ω_j $(\sum_{j=1}^{n} w_j = 1)$, which is assumed to be positive. The proposed methodology uses Rank-Order Centroid (ROC) method (Barron and Barrett, 1996) to assign the weights to the criteria. Approximate weighting schemes are a branch of objective methods. Equal weights (EW) (Dawes and Corrigan (1974), rank reciprocal (RR) (Stillwell et al., 1981), rank sum (RS) (Stillwell et al., 1981), rank exponent (RE) (Stillwell et al., 1981), rank-order centroid (ROC) (Barron and Barrett, 1996), geometric weights (GW) (Lootsma, 1999), and variable-slope linear (VSL) (Alfares and Duffuaa, 2008) belong to the approximate weighting branch. Barron and Barrett (1996) found that weights obtained in ROC manner were very stable. Additionally, Ahn and Park (2008) performed a simulation study on the approximate weighting schemes. They found out that the ROC method appears to be the best performer throughout the simulation. They argued that a common conclusion of many studies was that ROC weights had an appealing theoretical rationale and appeared to perform better than the other rank-based schemes in terms of choosing accuracy. There are 2 steps in the ROC procedure:

Step 1:The experts should rank the criteria in order of importance. Therefore, we may assume that the weights are uniformly distributed in the rank order of $w_{r1} \geq w_{r2} \geq w_{r3} \geq w_{rm}$, where r_j is a rank position of w_{rj}.

Step 2: With the use of Equation (2), the analyst calculates the weights of the criteria. This formula produces an estimate of the weights; this estimate minimizes the maximum error of each weight by identifying the centroid of all possible weights maintaining the rank order of the objective importance.

$$w_j = \frac{1}{n}\sum_{k=j}^{n} \frac{1}{rk} \tag{2}$$

Stage IV: the proposed methodology utilizes additive ratio assessment (ARAS) method (Zavadskas et al., 2010) to select the best choice among alternatives. ARAS method is based on the argument that the phenomena of complicated world could be understood by using simple relative comparisons. It is argued that the ratio of the sum of normalized and weighted values of criteria, which describes the alternative under consideration, to the sum of the values of normalized and weighted criteria, which describes the optimal alternative, is the degree of optimality, which is reached by the alternative under comparison. According to the ARAS method, a utility function value determining the complex relative efficiency of

Table 1- Main features of the alternative fuels/engines.

Fuel/Engine	Overall Features	References
CD	• Employed all over the world; • The most efficient among all the existing internal combustion engines; • Low purchasing costs; • The flexibility towards the speed of traffic; • The low sensitivity to road facility; • Very high exhaust emission rates (PM, NOx, CO, and CO2);	Farkas, 2013
ULSD	• Producing lower emissions (enabling catalytic converters to be used, which, in turn, lowers CO, NOx, and HC emissions); • Emission treatments such as particulate filters and oxidation catalysts reduce the emissions of ozone-forming compounds (NOx and HC) and trap and eliminate particulate matter (PM);	Gifford, 2003; Kassel and Bailey, 2004; Patil et al., 2010
BD	• Biodiesel has higher brake-specific fuel consumption compared to diesel, which means more biodiesel fuel consumption is required for the same torque; • BD has been found to provide the maximum increase in thermal efficiency; • BD has low brake-specific energy consumption; • It has lower harmful emissions than diesel;	Fazal et al., 2011; Omidvarborna et al., 2014
CNG	• Commercialized around the world; • Matured in its technology: • Clean burning qualities (CNG vehicles emit only slight amounts of carbon dioxide and carbon monoxide); • A wide resource base; • It generally costs 15–40% less than gasoline or diesel; • Reduction in operational and maintenance cost; • Easy conversion of conventional vehicles to operate in a CNG mode; • It has approximately 25% of the energy density of gasoline;	Uz, 2012; Farkas, 2013; Mousaei and Hatefi, 2015; Patil et al., 2010
LPG	• LPG is easy to transport and store; • It has a higher heating value, allowing you to heat your home at a lower price; • LPG does not contain sulfur, so it burns a lot cleaner than energy resources like oil; • It burns consistently, making it more reliable than other forms of energy; • LPG is also perfect for those who do not have access to NG lines; • There are few countries that have used LPG for public transportation; • LPG is suitable for medium and small vehicles;	Farkas, 2013; Sperling, 1995; Shah et al., 2017
LNG	• Good safety records; • Widely used across industries; • It is nontoxic and non-corrosive; hence, it will not pollute land or water on leakage into the environment; • High ignition temperature (it is more difficult than many other common fuels to be set on fire); • On release, LNG vaporizes into a lighter-than-air gas, which quickly disperses into the atmosphere;	Uz, 2012; Mousaei and Hatefi, 2015
DME	• Producing low levels of NOx emissions and low smoke levels when compared to petroleum-derived diesel fuels; • Clean-burning, sulfur-free, with extremely low particulate emissions; • No corrosion in pipelines, when transported; • Good ignition quality; • It rapidly decomposes into CO2 and water in the atmosphere without forming ozone; • Distribution of DME as fuel is easy due to the use of LPG infrastructure;	Nylund and Koponen, 2012; Mousaei and Hatefi, 2015
GTL	• Increased power compared with diesel; • Lower brake-specific fuel consumption for GTL fuel and its blends compared with diesel alone; • Less environmental impact (it contains low sulfur and low aromatic compounds); • GTL fuel and its blends had a slight reduction in NOx emissions and a significant reduction in CO, hydrocarbon, and smoke emissions compared with diesel;	Gyetvay, 2012; Sajjad et al., 2014; Mousaei and Hatefi, 2015
HCNG	• Lower overall pollutant emissions than CNG (66% reduction in unburned HC, 32% reduction in NOx, 17% reduction in CO, and 13% reduction in CO2). • Many cities in the world are experimenting with HCNG. • Problems associated with the on-board storage of hydrogen have resulted in a limited vehicle range;	Nagalingam et al., 1983; Patil et al., 2010
H2FC	• Broad surface in the burning chamber; • Low burning temperature; • Easily made inflammable; • No detrimental substance is produced and only pure water, in the form of air, is emitted; • Hydrogen is not suitable for onboard storage; • Hydrogen's energy density is very low compared to that of the methanol and especially gasoline (a fully loaded fuel tank can last as far as 250 km); • It generally requires very large and heavy tanks on board of the vehicle; • It would be necessary to create an entire new infrastructure, i.e. to set up refueling stations;	Farkas, 2013
MG	• The capability of continuous traveling by use of FFV is inferior to conventional vehicles; • Significantly reduce vehicle emissions of pollutants and greenhouse gases; • The thermal energy of MG is lower than that of the gasoline;	Tzeng, 2005; Farkas, 2013
OC	• The vehicle is charged immediately after it is plugged in; • OC method does not fully utilize the renewable energy; • The lowest electricity price for OC is about 11% higher than the annual average electricity price; • The number of fleet vehicles required to operate a particular route is potentially lower for OC scheme compared to the conventional charging scenario;	Bosshard, 2015; Zhang and Markel, 2016;

Table 2- The selected criteria to evaluate fuel/engine modes

Criterion	Sub-criterion	Code	Description	References
Performance	Energy Supply	ES	It is based on the yearly amount of energy that can be supplied, on the reliability of energy supply, on the reliability of energy storage, and on the cost of energy supply.	Tzeng et al., 2005
	Energy Efficiency	EE	It represents the efficiency of fuel energy.	Tzeng et al., 2005; Farkas, 2013
	Flow Speed of Traffic	FS	It compares the average speed of alternative vehicles for certain traffic. If the speed of traffic flow is higher than the vehicle speed, the vehicle would not be suitable to operate on certain routes.	Tzeng et al., 2005
	Vehicle Capability	VC	The cruising distance, slope climbing, and average speed;	Tzeng et al., 2005
Environmental	Air Pollution	AP	The extent to which a fuel mode contributes to air pollution since vehicles with diverse modes of fuel impact on air differently;	Tzeng et al., 2005; Mousaei and Hatefi,2015
	Soil Pollution	SP	The extent to which an alternative fuel contributes to soil pollution;	Mousaei and Hatefi, 2015
	Water Pollution	WP	The degree to which a fuel has negative impacts on water resources;	Mousaei and Hatefi, 2015
	Noise Pollution	NP	The noise produced during the operation of the vehicle;	Tzeng et al., 2005
Economical	Implementation Cost	IC	The costs of production and implementation of alternative vehicles;	Tzeng et al., 2005; Vafaeipour et al., 2014; Mousaei and Hatefi, 2015
	Maintenance Cost	MC	The maintenance costs for alternative vehicles;	Tzeng et al., 2005; Vafaeipour et al., 2014
	Distance to Market	DM	Distance between the potential production site and the region of consumption;	Mousaei and Hatefi, 2015
	Transportation Easiness	TE	Is the fuel easy or hard to transport?	Current work
	Storing Easiness	SE	Is the fuel easy or hard to store?	Current work
	Consumption Trend	CT	The overall trend of consumption of alternative vehicles;	Mousaei and Hatefi, 2015
	World Trends	WT	Which alternatives are the big countries/oil companies talking about and focusing on?	Mousaei and Hatefi, 2015
	Purchase Price	PP	The purchase price of the fuel;	Farkas, 2013
Infrastructure	Road Facility	RF	The road features needed for the operation of alternative vehicles (like pavement and slope);	Tzeng et al.,2005
	Industrial Availability	IA	The present industrial infrastructures to produce and implement alternative vehicles;	Farkas, 2013
Technological	Technology Maturity	TM	The maturity and availability of related technology;	Mousaei and Hatefi, 2015; Farkas, 2013
	Safety Issues	SI	The safety aspects of alternative vehicles;	Farkas, 2013
	Industrial Relationship	IR	The relationship of each alternative to other industrial production is taken as the criterion;	Tzeng et al., 2005
Social	Social Acceptability	SA	Degree to which the community accept alternative vehicles;	Vafaeipour et al., 2014
	Comfort Sense	SC	The particular issue regarding the sense of comfort and the fact that users tend to pay attention to the accessories of the vehicle (air-conditioning, automatic door, etc.);	Tzeng et al., 2005
Risk	Political Risks	PR	Risks and uncertainties related to political issues;	Vafaeipour et al., 2014
	Economical Risks	ER	Risks and uncertainties related to economic issues;	Vafaeipour et al., 2014
	Social Risks	SR	Risks and uncertainties related to social issues;	Current work

a reasonable alternative is directly proportional to the relative effect of values and weights of the main criteria considered in a project. The ARAS method is conducted through 6 steps.

Step 1: determine the optimal performance score (called ideal solution) for each criterion. This value may be even greater than 9 (the score for the best case). If the experts do not have any preference, the optimal performance ratings are calculated by Equation (3).

Step 2: Calculate the normalized decision-matrix. The normalized performance ratings are calculated using Equation (4).

Step 3: Calculate the weighted normalized decision-matrix. The weighted normalized performance ratings are calculated using Equation (5).

Step 4: calculate the overall performance rating, for each alternative. This index can be calculated using Equation (6).

Step 5: Calculate the degree of utility for each alternative. When evaluating alternatives, it is not only important to determine the best ranked alternative, but also to determine the relative performances of considered alternatives in relation to the optimal alternative. For this purpose, the degree of utility is used, and it can be calculated using Equation (6).

Step 6: rank fuel modes and/or select the most efficient one. The considered modes are ranked by ascending Q_i, i.e. the alternative with the largest value of Q_i is the best place (Equation (6)).

$$x_{0j} = \max_i \{x_{ij}\} \tag{3}$$

$$y_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{4}$$

$$v_{ij} = w_j \times y_{ij} \tag{5}$$

$$S_i = \sum_{j=1}^{n} v_{ij} \tag{6}$$

$$Q_i = \frac{S_i}{S_0} \tag{7}$$

$$A_i^* = \{A_i \mid \max_i Q_i\} \tag{8}$$

It should be noted that the relevant experts are taken part in four activities. In the first one, they determine the criteria and the alternatives as in Stage 1. Thereafter, in Stage 2, they assign a score to each alternative on each criterion. In the third activity, the experts give the sort of criteria in Step 1 of Stage 3. Finally, in Step 1 of Stage 4, they can determine the optimal performance score for each criterion if they have any idea. A DELPHI technique is suggested to get the consensus with regard to all the information provided by the experts.

Table 3- The ARAS calculations as Stage IV of the proposed methodology

Criteria Names		AP	WP	SP	NP	IC	MC	DM	CR	SR
Criteria Weights		0.148	0.061	0.042	0.026	0.314	0.203	0.012	0.111	0.083
x_{ij}	LPG	1	4	4	1	9	7	7	3	8
	MG	3	3	5	1	3	7	6	7	8
	CNG	5	7	7	7	5	5	5	5	9
	CD	8	8	9	7	2	1	1	5	5
	HCNG	9	6	8	8	3	5	4	2	7
x_{0j}	Ideal	9	8	9	8	9	7	7	7	9
Column Summation		35	36	42	32	31	32	30	29	46
y_{ij}	LPG	0.0286	0.1111	0.0952	0.0313	0.2903	0.2188	0.2333	0.1034	0.1739
	MG	0.0857	0.0833	0.1190	0.0313	0.0968	0.2188	0.2000	0.2414	0.1739
	CNG	0.1429	0.1944	0.1667	0.2188	0.1613	0.1563	0.1667	0.1724	0.1957
	CD	0.2286	0.2222	0.2143	0.2188	0.0645	0.0313	0.0333	0.1724	0.1087
	HCNG	0.2571	0.1667	0.1905	0.2500	0.0968	0.1563	0.1333	0.0690	0.1522
	Ideal	0.2571	0.2222	0.2143	0.2500	0.2903	0.2188	0.2333	0.2414	0.1957
v_{ij}	LPG	0.0042	0.0068	0.0040	0.0008	0.0912	0.0444	0.0028	0.0115	0.0144
	MG	0.0127	0.0051	0.0050	0.0008	0.0304	0.0444	0.0024	0.0268	0.0144
	CNG	0.0211	0.0119	0.0070	0.0057	0.0506	0.0317	0.0020	0.0191	0.0162
	CD	0.0338	0.0136	0.0090	0.0057	0.0203	0.0063	0.0004	0.0191	0.0090
	HCNG	0.0381	0.0102	0.0080	0.0065	0.0304	0.0317	0.0016	0.0077	0.0126
	Ideal	0.0381	0.0136	0.0090	0.0065	0.0912	0.0444	0.0028	0.0268	0.0162
S_i	S_{LPG}=0.1801 S_{MG}=0.1420 S_{CNG}=0.1654 S_{CD}=0.1172 S_{HCNG}=0.1467 S_{Ideal}=0.2485									
Q_i	Q_{LPG}=0.7247 Q_{MG}=0.5714 Q_{CNG}=0.6657 Q_{CD}=0.4714 Q_{HCNG}=0.5904									
Rank	LPG>CNG>HCNG>MG>CD									

Table 4- Comparing the results of this research with other respective investigations

Poh and Ang, 1999	AHP	Singapore / Transportation	Supply; Emission; Technology; Cost; Consumer Preference; Safety.
Winebrake and Creswick, 2003	AHP Scenario Analysis	Transportation	Operation (Start-up, Range, Power, Safety, Response); Distribution (Capacity, Health, Convenience); Resources (Dependency, Sustainability); Economics (Vehicle, Infrastructure, Fuel); Environment (Greenhouse gases, Local Air, Land Use, Distribution).
Tzeng et al., 2005	AHP TOPSIS VIKOR	Taiwan / Public Transport	Energy Supply; Energy Efficiency; Air Pollution; Noise Pollution; Industrial Relationship; Costs of Implementation; Costs of Maintenance; Vehicle Capability; Road Facility; Speed of Traffic Flow; Sense of Comfort.
Patil et al.,2010	Pros and Cons Analysis	Nigeria / Public Transport	Purchase Price; Availability; Emissions; Technology; Safety; Performance; Summary.
Vahdani et al., 2011	Fuzzy MCDM TOPSIS	Iran / Public Transport	Like Tzeng et al., 2005
Farkas, 2013	MAROM	Taiwan / Public Transport	Like Tzeng et al., 2005
Patil et al., 2014	Pros and Cons Analysis	Nigeria / Public Transport	Like Patil et al., 2010
Farkas, 2014	AHP TOPSIS MAROM	Taiwan / Public Transport	Like Tzeng et al., 2005
Mousaei and Hatefi, 2015	TOPSIS	Iran / General Applications	Distance to Market; Internal Demand Increment; Consumption Trend; Big Companies Concentration; Impact on Environment; Cleanness for Gasoline Type Engines; Cleanness for Diesel Engines; Capital Cost; Energy Density; Market Price; NG Reserves; Technology Maturity; Efficiency.
Shah et al., 2017	Pros and Cons Analysis	Bangladesh / Automobile Fuel	Calorific Value; Tariff/Rate/Cost; Cost of Energy.
The Current Study	ROC ARAS DELPHI	Iran / Public Transport	Performance (Energy Supply, Energy Efficiency, Flow Speed of Traffic, Vehicle Capability); Environmental (Air Pollution Soil Pollution, Water Pollution, Noise Pollution); Economical (Implementation Cost, Maintenance Cost, Distance to Market, Transportation Easiness, Storing Easiness, Consumption Trend, World Trends, Purchase Price); Infrastructure (Road Facility, Industrial Availability); Technological (Technology Maturity, Safety Issues, Industrial Relationship); Social (Social Acceptability, Comfort Sense); Risk (Political Risks, Economical Risks, Social Risks).

5. The Numerical Case

A sample location is considered to numerically analyze the proposed model. Regarding the aforesaid description as in Stage 1, the options (m=5) are LPG, MG, CNG, CD, and HCNG, and the criteria (n=9) are AP, SP, WP, NP, IC, MC, DM, CR, and SR. Next, the decision-making matrix with the score x_{ij} (i=1,..,5;j=1,..,9) was formed as given by Equation (7). In this matrix, rows 1 to 5 are related to the candidates LPG, MG, CNG, CD, and HCNG, and columns 1 to 9 are concerned with AP, SP, WP, NP, IC, MC, DM, CR, and SR respectively.

$$\begin{bmatrix} 1 & 4 & 4 & 1 & 9 & 7 & 7 & 3 & 8 \\ 3 & 3 & 5 & 1 & 3 & 7 & 6 & 7 & 8 \\ 5 & 7 & 7 & 7 & 5 & 5 & 5 & 5 & 9 \\ 8 & 8 & 9 & 7 & 2 & 1 & 1 & 5 & 5 \\ 9 & 6 & 8 & 8 & 3 & 5 & 4 & 2 & 7 \end{bmatrix} \quad (9)$$

The ranking order of the criteria respecting the experts' opinions is IC>MC>AP>CR>SR>WP>SP>NP>DM. This results in the ROC weights of 0.314, 0.203, 0.148, 0.111, 0.083, 0.061, 0.042, 0.026, and 0.012 for the nine criteria respectively. Table 3 presents the rest of calculations in turn for the ARAR method.

6. Conclusions

Energy challenges such as environment pollution, governmental regulations, and technological aspects have directed the respected researchers on selecting the best alternative fuels for public transport. Following previous researches, this paper was a trial in this field. Table 4 compares the results of the current research with the outcomes of some similar cases.

As the first contribution, the current study considers several types of fuels as alternatives and a fairly comprehensive list of decision criteria. The paper used a hybrid multi-criteria analysis method to assess decision-making matrix. The methodology used the ROC technique to determine the criteria weights instead of eliciting the weights from the experts. In fact, the experts are needed to only have minimal knowledge about the preference of criteria. The ROC is the best schemes among "approximate weighting" methods. The paper also benefits the new ARAS method to rank alternatives; in the decision-matrix, the experts are asked to give scores between 1 and 9 instead of inaccessible detailed quantitative data, and this approach could be considered as another aspect of the applicability of the proposed method. The suggested methodology was applied in given location, as a case study, with data provided by the experts from the relevant engineering fields. The result showed that the LPG is the most suitable fuel mode for that location area under the study. In summary, the overall results presented LPG>CNG>HCNGS>MG>CD in terms of closeness to the ideal point of the ARAS method. Moreover, by dint of the easiness and flexibility of the proposed methodology, it can help the public transport analysts to deal with the complicated fuel mode selection problems in the most effective and efficient manner.

For the future research works, the recommendations are as the following:

1. Focusing on a variation of the proposed methodology and a real case study and using some open interviews with respected experts to derive the alternatives and the criteria; next, making a quantitative questionnaire to demonstrate the validity of the findings;
2. Employing risk analysis tools to deeply analyze the risks of the fuel candidates and providing comprehensive responses to handle the identified risk factors.

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