Chapter 5
Green Transport Fleet Appraisal

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Abstract One effective approach to improve the environmental burdens of logistics and transport operations is to ensure that evaluation and selection of transportation vehicles for organizations incorporate green attributes. The availability of different types of vehicles with varying performance characteristics as well as the breadth of environmental performance metrics have made the transport fleet decision making more complex and dynamic. This chapter presents a multi-criteria decision-making (MCDM) approach, integrating Rough Set theory and VIKOR method, for sustainable transportation vehicles selection. First, the related sustainability attributes are identified from the existing literature to be added to the conventional performance-based and economic vehicle evaluation criteria. The MCDM approach is then used for ranking and selecting the sustainable transportation vehicles. A numerical example is finally presented to illustrate the application of the proposed approach.

Keywords Sustainable transportation fleet · Green · Environmental sustainability · Transportation vehicle · Rough set theory · VIKOR

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5.1 Introduction

Demand for logistics and transportation services has increased rapidly along with the global economic growth and strengthen supply chain cooperation. Transportation vehicles have consequently become one of the major fossil-fuel consumers and source of air pollution emissions (Takeshita 2012; Yan and Crookes 2010). In response to regulatory and competitive pressures, the evaluation and selection of more sustainable transportation vehicles have gained increasing attention by organizations in various industries (Bae et al. 2011). Many transportation and logistics providers have started adopting alternative-fuel vehicles. For example, UPS and FedEx are experimenting with all-electric vehicles with a range of over 50 miles (King 2013). In addition to the logistics industry, companies in the retail industry (e.g. Wal-Mart), telecommunications and utilities industry (e.g. AT&T and Verizon), beverage industry (e.g. Coca-Cola and Pepsi), and even forestry and banking industries have planned for sustainable transportation fleet strategies (Bae et al. 2011).

Most sustainable transportation vehicles rely on alternative fuel sources such as electricity, solar, wind, bio-fuels, and compressed natural gas (Capasso and Veneri 2014; Rose et al. 2013; Mabit and Fosgerau 2011; Arsie et al. 2010). Depending on the type of alternative fuels, every transportation vehicle type (e.g. full electric vehicles, hydrogen/fuel cell vehicles, and internal combustion/electric hybrids) has its operational, environmental, and economic strengths and weaknesses. Therefore, organizations need to evaluate the transport fleet requirements given their internal economic goals and sustainability strategies. Although there has been some effort to identify the attributes of alternative-fuel vehicles selection (Hsu et al. 2014; Awasthi et al. 2011; Tzeng et al. 2005), a holistic framework does not exist. The adoption of alternative-fuel vehicles requires a holistic consideration of economic, environmental and social dimensions when making important purchasing decisions (Byrne and Polonsky 2001). Yet, research on modeling transport fleet management has been rather limited and studies focusing on managing sustainable vehicle appraisal are virtually non-existent. In this chapter, we introduce a multi-criteria decision-making (MCDM) model, integrating Rough Set theory and the VIKOR method, for green transport fleet appraisal.

In the next section, we start the chapter by providing some background information on sustainability-based corporate transport fleet evaluation and selection. The hybrid MCDM model is then introduced. An illustrative example is provided to build comprehension of the multi-methodology technique. Insights, implications, limitations and future research directions are discussed in the concluding section.

5.2 Literature on Sustainability-Based Transportation Vehicle Fleet Selection

Conventional transportation vehicle selection practices have ignored the systematic inclusion of sustainability attributes (Bai et al. 2012). The literature on sustainable transportation vehicle fleet management is rather limited. To develop a framework for sustainable evaluation and selection of vehicle types, we review some of the major sustainability attributes used in the literature including sustainable transportation systems, transportation modes, and alternative-fuel vehicle characteristics (Do et al. 2014; Bai and Sarkis 2013, 2014; Litman 2013; Bae et al. 2011; Awasthi et al. 2011; Yan and Crookes 2010; Gehin et al. 2008; Zhao and Melaina 2006; Litman and Burwell 2006; Litman 2005; Byrne and Polonsky 2001; Deakin 2001). We classify the identified attributes in eight categories including vehicle characteristics, policies and regulations, pollution emissions, resources consumption, infrastructure, recycling scrap, employees, and scalability. A total of 51 attributes and measures are considered under these categories. Table 5.1 summarizes the results and the related literature support for each attribute.

Table 5.1 Attributes for sustainable vehicle evaluation and selection

Category	Attributes	Related literature
Vehicle characteristics	Vehicle price	Zhao and Melaina (2006)
	Maintenance costs	Zhao and Melaina (2006)
	Running costs	Awasthi et al. (2011)
	Travelling speed range	Litman and Burwell (2006)
	Driving range (e.g. high-speed roads, hills)	Litman and Burwell (2006)
	Traffic safety	Litman (2005)
	Quality of service (e.g. breakdown rate)	Litman (2013)
	Loading capacity	Litman (2013)
	Requirements for goods specifications (e.g. size, shape)	Litman (2013)
	Information technology (e.g. routing or scheduling systems)	Deakin (2001)
	Technical innovation for improved efficiency	Litman and Burwell (2006)
Policies and regulations	Compliance with energy-base government regulations	Byrne and Polonsky (2001)
	Compliance with emission-based government requirements	Byrne and Polonsky (2001)
	The use of hazardous substances (RoHS)	Gehin et al. (2008)
	The use of volatile organic compounds (VOCs)	Do et al. (2014)
	Tax relief benefits	Byrne and Polonsky (2001)
	Fuel subsidies	Byrne and Polonsky (2001)

(continued)

Table 5.1 (continued)

Category	Attributes	Related literature
	Governments subsidies or incentives	Zhao and Melaina (2006)
Pollution emissions	CO_2 emissions rate	Awasthi et al. (2011)
	GHG emissions rate	Awasthi et al. (2011)
	Noise pollution rate	Awasthi et al. (2011)
	Solid or water waste generation	Litman and Burwell (2006)
	Other air pollutants (e.g. NOx, VOCs, CO, particulates, toxics)	Awasthi et al. (2011)
Resources	Unit fuel cost	Byrne and Polonsky (2001)
	Sufficient fuel supply	Byrne and Polonsky (2001)
	Alternative fuels	Byrne and Polonsky (2001)
	Energy saving	Awasthi et al. (2011)
	Fossil fuel usage rate	Awasthi et al. (2011)
	Renewable energy use	Awasthi et al. (2011)
	Fuel efficiency	Litman and Burwell (2006)
	Clean technologies	Zhao and Melaina (2006)
	Fuel safety	Awasthi et al. (2011)
Infrastructure	Market availability of the vehicle	Byrne and Polonsky (2001)
	Availability of fuels	Byrne and Polonsky (2001)
	Availability of fuel delivery outlets	Byrne and Polonsky (2001)
	Availability of maintenance services	Byrne and Polonsky (2001)
	Financing and lending policies	Zhao and Melaina (2006)
	Transportation easements (e.g. lower transportation tolls)	Byrne and Polonsky (2001)
Recycling	Vehicle compliance with ELV (end-of-life vehicle)	Gehin et al. (2008)
	Vehicle compliance with WEEE	Gehin et al. (2008)
	Waste from end-of-life vehicle or used tires	Gehin et al. (2008)
	Recycling costs	Gehin et al. (2008)
	Recyclability rate	Gehin et al. 2008
	Dismantling and reuse possibility	Gehin et al. (2008)
	Recycled materials usage	Gehin et al. (2008)
Employees	Health and safety	Litman and Burwell (2006)
	Comfort of use (e.g. comfortable seats, accessories)	Tzeng et al. (2005)
	Personnel training	Russo and Comi (2010)
	Availability of technical support staff	Russo and Comi (2010)
Scalability	The impact of weather changes on vehicle operations	Abkowitz (2002)
	The impact of road conditions on vehicle operations	Litman and Burwell (2006)
	Vehicle operation in disasters	Abkowitz (2002)

A range of approaches have been adopted for sustainability evaluation of transportation vehicles. Some of these approaches include life cycle analysis (LCA) (Wang et al. 2013; Nanaki and Koroneos 2012), cost-benefit analysis (CBA) (Damart and Roy 2009), cost-effectiveness analysis (CEA) (Wood 2003), environmental impact assessment (EIA) (Fischer 2002), optimization and mathematical programming models (Mula et al. 2010; Shah et al. 2012), system dynamics models (Wang et al. 2008), assessment indicator models (Phillis and Andriantiantsaholiniaina 2001), game theoretic models (Bae et al. 2011) and multi-criteria decision analysis (MCDA) methods (Awasthi et al. 2011).

A number of combined approaches have been recently developed to overcome the weaknesses of individual approaches. For example, Yedla and Shrestha (2003) rank alternative transport options by means of analytic hierarchy process (AHP) using weighted arithmetic mean method (WAMM) for group aggregation. Tzeng et al. (2005) apply TOPSIS and VIKOR to find the best compromise alternative-fuel bus with the relative weights of evaluation criteria determined by AHP.

Despite the importance of greening corporate fleets, none of the above methods have been used for sustainability evaluation of transportation vehicles. We introduce in this chapter a methodology that can be used to evaluate the sustainability performance of vehicles using the attributes defined in Sect. 2.1. This approach involves the integration of Rough Set theory and the VIKOR method to evaluate the importance of sustainability attributes of vehicles.

5.3 A Hybrid MCDM Approach

This section presents the foundational elements for the hybrid MCDM approach and introduces the background on the various mathematical developments and notations. The two major elements of the proposed approach include Rough Set theory and the VIKOR method.

5.3.1 Rough Set Theory

Rough set theory (Pawlak 1982), is an analytical approach for managing vagueness and ambiguity. The method classifies objects into similarity classes (clusters) containing objects that are indiscernible with respect to previous occurrences and knowledge. These similarity classes are then employed to determine various patterns within the data. Rough set theory has been utilized for sustainable supply chain and operations management applications (Bai and Sarkis 2010a, b, 2014). Some particulars of Rough Set theory, for later integration, are now introduced with notation and definitions.

Definition 5.1 Let $S = (U, R)$ be an approximation space, where U is a non-empty finite universe and R is an equivalence relation on U. An approximation space $S = (U, R)$ can be regarded as a knowledge base about U.

The equivalence relation R can be defined that two objects are equivalent if and only if they have the same value on every attribute based on a set of attributes (Pawlak 1991). The equivalence class, which are called elemental information granules in the approximation space, contain an object $x(x \in U)$ defined as $[x]_R = \{ y | y \in U, xRy\}$.

Definition 5.2 Given any equivalence relation R and any subset $X \in U$, we can define a lower approximation of X in U and an upper approximation of X in U by the following expressions:

$$\underline{R}X = \{x \in U | [x]_R \subseteq X\} \tag{5.1}$$

and

$$\bar{R}X = \{x \in U | [x]_R \cap X \neq \phi\} \tag{5.2}$$

Approximation vagueness is usually defined by precise values of lower and upper approximations. Lower approximations $POS_R(X) = \underline{R}X$ describe the object domain that definitely belongs to the subset of interest. Upper approximations describe objects which may possibly belong to the subset of interest. The difference between the upper and the lower approximations constitutes a boundary region $BND_R(X) = \bar{R}X - \underline{R}X$ for the vague set. Hence, Rough Set theory expresses vagueness by employing a boundary region of a set. If the boundary region of a set is empty, $BND_R(X) = 0$, the set is crisp; otherwise, the set is rough (inexact).

5.3.2 VIKOR Method

The VIKOR method was developed for multi-criteria optimization and compromise solutions of complex systems (Opricovic and Tzeng 2002, 2004). It is a discrete alternative multiple criteria ranking and selection approach based on a particular measure of proximity to an ideal solution. VIKOR focuses on ranking of solutions in the presence of conflicting criteria helping decision-makers select the "best" compromise solution (Opricovic and Tzeng 2007).

The multi-criteria measure for compromise ranking is developed from the L*p*-metric used as an aggregating function in a compromise programming method (Yu 1973). Let i = 1, 2, …, m and $F_1, F_2, \ldots, F_m$ denote the m alternatives facing a decision-maker. Let j = 1, 2, …, n, with n being the number of criteria. Then the performance score for alternative F_i with respect to the jth criterion is denoted by f_{ij}.

Let w_j be the weight on the jth criterion which expresses the relative importance of that criterion. Development of the VIKOR method starts with the following form of the Lp-metric:

$$L_{p,i} = \{\sum_{j=1}^{n} [w_j(\left|f_j^+ - f_{ij}\right|)/(\left|f_j^+ - f_j^-\right|)]^p\}^{1/p}, \quad 1 \leq p \leq \infty;\ i = 1,\ldots,m \tag{5.3}$$

where f_j^+ represents the highest performance score with respect to the jth criterion among all alternatives. Likewise, f_j^- represents the lowest performance score with respect to the jth criterion. $L_{1,i}$ (as S_i) and $L_{\infty,i}$ (as Q_i) are used to formulate ranking measures.

$$S_i = L_{p=1,i} = \sum_{j=1}^{n} [w_j(\left|f_j^+ - f_{ij}\right|)/(\left|f_j^+ - f_j^-\right|)] \tag{5.4}$$

$$Q_i = L_{p=\infty,i} = \max_j [w_j(\left|f_j^+ - f_{ij}\right|)/(\left|f_j^+ - f_j^-\right|)] \tag{5.5}$$

VIKOR ranks the alternatives by sorting the values of S_i, Q_i and R_i, for $i = 1, 2, \ldots, m$, in decreasing order.

$$R_i = v(S_i - S^+)/(S^- - S^+) + (1 - v)(Q_i - Q^+)/(Q^- - Q^+) \tag{5.6}$$

where $S^+ = \min_i S_i, S^- = \max_i S_i, Q^+ = \min_i Q_i, Q^- = \max_i Q_i$ and v is introduced as a weight on the strategy of maximum group utility (average gap in scale normalization), whereas $1-v$ is the weight of the individual regret (maximal gap in special criterion for priority improvement).

Opricovic and Tzeng (2004) propose a compromise solution, for a transportation vehicle in this case, (A(1)), which is ranked by the measure R (minimum) when the following two conditions are satisfied:

C1. Acceptable advantage:

$$R(A(2)) - R(A(1)) \geq 1/(m - 1), \tag{5.7}$$

where $A(2)$ is the alternative positioned second in the ranking list by R and m is the number of alternatives.

C2. Acceptable stability in decision making:

The alternative $A(1)$ must also be the best ranked by S and/or Q. This compromise solution is stable within a decision making process, which could be the strategy of maximum group utility (when v > 0.5 is needed), or “by consensus” v ≈ 0.5, or "with veto" (v < 0.5). Here, v is the weight of the decision making strategy of maximum group utility.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed consisting of:

- Alternatives $A(1)$ and $A(2)$ if only the condition C2 is not satisfied, or
- Alternatives $A(1)$, $A(2)$, …, A(M) if the condition C1 is not satisfied; A(M) is determined by the relation $R(A(M)) - R(A(1)) < 1/m$ for maximum M (the positions of these alternatives are "in closeness").

5.4 Application of the Hybrid MCDM Approach: An Illustrative Example

We now illustrate the application of the proposed hybrid methodology for evaluation and selection of sustainable transportation vehicles using example, hypothetical data.

Step 1: *Construct the Original Decision System*

To start evaluating and ranking transportation vehicles based on various sustainability metrics, a decision table is constructed for the potential alternatives (see Table 5.2). For the sake of this example, a total of six potential vehicle alternatives, $U = \{F_{\mathrm{i}}, \mathrm{i} = 1, 2, \ldots, 6\}$ is considered. The performance of each vehicle alternative is weighted against 18 attributes $C = \{c_j, j = 1, 2, 3, \ldots, 11\}$. The attributes outlined in Table 5.1 were used as the starting point and were further refined to reflect the current transport vehicle fleet selection practice.

Step 2: *Determine the performance of each vehicles against the sustainability attributes*

The performance of each vehicle is then evaluated against the identified attributes. Some of this data is related to crisp values (such as the vehicle price), and others are scaled in linguistic perceptual scores such as very poor, medium/average, good and very good. The hypothetical data is shown in Table 5.2.

Step 3: *Normalize the Information Decision System*

For consistency in evaluations, a normalization procedure is introduced such that sustainability attributes and all the later calculations, such as distance measures, use similar scales. Note that some of these raw values are in crisp (regular) form and some are based on qualitative judgments. This normalization will adjust all the sustainability attribute values for each alternative (f_{ij}) to be $0 \leq f_{ij} \leq 1$.

Table 5.2 Information system table: the performance of each vehicle

Vehicles type	Vehicle characteristics			Pollution emissions		Policies and regulations		Resources		Infrastructure	
	Vehicle price	Travelling speed range	Safety features	CO_2 emissions rate	Noise pollution rate	Compliance with government regulations	Governments subsidies/ incentives	Alternative fuel	Energy consumption rate	Availability of fuels	Availability of maintenance services
Vehicle 01	$84,000	70	VG	VG	VG	VG	$2000	VP	VG	VG	MG
Vehicle 02	$74,000	70	G	MG	VG	VG	$0	VP	G	VG	VG
Vehicle 03	$70,000	70	MG	M	G	VG	$0	VP	G	VG	M
Vehicle 04	$68,000	70	M	M	G	VG	$0	VP	MG	VG	M
Vehicle 05	$65,000	70	M	MP	G	VG	$0	VP	M	VG	M
Vehicle 06	$52,000	70	P	VP	MG	G	$0	VP	P	VG	M

Step 3.1: *Transform linguistic values into crisp numbers*

All values are transformed into a number crisp f. For the linguistic or qualitative form, we introduce a crisp numerical scale table that would correspond to the qualitative values given by the decision makers. Seven linguistic variables, namely "very good", "good", "medium good", "medium", "medium poor", "poor" and "very poor", are used to assess the level of the performance criteria. This seven-level scale is shown in Table 5.3. The qualitative variables and natural language variables are transformed into crisp numbers.

Safety is an example of a qualitatively valued attribute, for which the transformation to a crisp number for vehicle 01 is given as: $F_{01\text{Safety}} = \text{VG} = 1$.

Step 3.2: *Normalize the numeric variables by membership function*

All the crisp values are now normalized. To address this issue a membership function, expressions (5.8) and (5.9) are introduced. Normalization of the incremental (beneficial) value is completed using the membership function in expression (5.8).

$$U(f_{ij}) = \begin{cases} 0 & \text{if } f_{ij} \le Lower, \\ v_{ij} & \text{if } Lower \le f_{ij} \le Upper, \\ & \text{where } v_{ij} = \frac{f_{ij} - Lower}{Upper - Lower} \\ 1 & \text{if } f_{ij} \ge Upper, \end{cases} \tag{5.8}$$

where f_{ij} is the specific evaluation value, *Lower* is the minimum historical value, and *Upper* is the maximum historical value for a factor.

The negative (decreasing) membership value of the crisp number is determined using the membership function in expression (5.9):

$$U(f_{ij}) = \begin{cases} 1 & \text{if } f_{ij} \le Lower, \\ v_{ij} & \text{if } Lower \le f_{ij} \le Upper, \\ & \text{where } v_{ij} = \frac{Upper - f_{ij}}{Upper - Lower} \\ 0 & \text{if } f_{ij} \ge Upper, \end{cases} \tag{5.9}$$

For vehicle price attribute (decreasing is better) of vehicle 01 which was exemplified in step 3.1, the normalization using expressions (5.9) is as follows:

Table 5.3 The linguistic variables and their corresponding crisp numbers

Linguistic variables	Crisp numbers
Very poor (VP)	0
Poor (P)	0.2
Medium poor (MP)	0.4
Medium(M)	0.5
Medium good (MG)	0.6
Good (G)	0.8
Very good (VG)	1

$$F_{01\text{Price}} = v_{11} = \frac{|f_1^{\max} - f_{11}|}{|f_1^{\max} - f_1^{\min}|} = \frac{|84,000 - 84,000|}{|84,000 - 52,000|} = 0;$$

Thus, the normalized value of crisp number for vehicle price attribute of vehicle 01 would be $F_{01\text{Price}} = 0$. We arrive at a normalized matrix v_{ij} from the original matrix f_{ij} with expressions identified in this step 3.2. The normalization process alters all normalized decision attributes to have increasing values representing better sustainability attributes. The resulting normalized values are shown in Table 5.4.

Step 4: *Determine information content of each attribute*

In the following steps we focus on the use of Rough Set theory to determine the importance (weight) of each attribute. The goal is to determine the various 'conditional attribute elementary sets' (X) for each vehicle. First, expression (5.10) is used to determine the level of information content across the conditional attributes (c) (Liang et al. 2006).

$$\text{I}(c) = 1 - \frac{1}{|U|^2} \sum_{i=1}^{|U|} |X_i^c| \tag{5.10}$$

where I(c) is the information content[1] for each conditional attribute, in the case of this study, it is each of the sustainability attributes. $|U|$ is the cardinality of the universe of vehicles. $|X_i^c|$ is the number of vehicles with similar attributes levels across the conditional attribute c for vehicle i. It is also defined as the number of members within the conditional attribute c for vehicle i.

Given lower approximation $\underline{R}X$ of a Rough Set from Definition 5.2, a lower approximation of X for attribute c can be determined using expression (5.11):

$$X_i^c = \{x_j \in U | d_c(x_i, x_j) \leq \delta\}, \tag{5.11}$$

where δ is the inclusion threshold value and $0 \leq \delta \leq 0.5$. In this case study, $\delta = 0.1$. That is, two vehicles i and j are members of the same set only if $d_c(x_i, x_j) \leq \delta$ for $c \in C$, where $d_c(x_i, x_j)$ denotes the distance measure of two transportation vehicle i and j for the value of attribute $c \in C$.

Take for example, the distance measure $d_{\text{Price}}(x_{03}, x_{04}) = 0.06$ between transportation vehicle 3 and 4 is less than 0.1. The distance measure $d_{\text{Price}}(x_{04}, x_{05}) = 0.09$ between vehicles 4 and 5 is also less than 0.1. Overall, $|X_{04}^{\text{Price}}| = 3$. Table 5.5 shows the listing of vehicle price attribute elementary set types and respective $|X_i^{\text{Price}}|$ values for each vehicle within that set. The various 'conditional attribute elementary set types' (X_i^c) for the vehicles are determined for the vehicle set when they have similar attributes levels across the conditional attribute c for a vehicle i.

[1]This term has also been defined as information entropy of a system (Liang and Shi 2004).

Table 5.4 Normalized values of all sustainability attributes

Vehicles type	Vehicle characteristics			Pollution emissions		Policies and regulations		Resources		Infrastructure	
	Vehicle price	Travelling speed range	Safety features	CO_2 emissions rate	Noise pollution rate	Compliance with government regulations	Governments subsidies/ incentives	Alternative fuel	Energy consumption rate	Availability of fuels	Availability of maintenance services
Vehicle 01	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00	0.20
Vehicle 02	0.31	0.00	0.75	0.60	1.00	1.00	0.00	0.00	0.75	0.00	1.00
Vehicle 03	0.44	0.00	0.50	0.50	0.50	1.00	0.00	0.00	0.75	0.00	0.00
Vehicle 04	0.50	0.00	0.38	0.50	0.50	1.00	0.00	0.00	0.50	0.00	0.00
Vehicle 05	0.59	0.00	0.38	0.40	0.50	1.00	0.00	0.00	0.38	0.00	0.00
Vehicle 06	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ideal vehicle	1.00		1.00	1.00	1.00	1.00	1.00		1.00		1.00

Table 5.5 Elementary sets for vehicle price attribute

Elementary set type	Members in elementary set type	Number in set ($\lvert X_i^{\text{Price}} \rvert$)
TYPE1	Vehicle 01	1
TYPE2	Vehicle 02	1
TYPE3	Vehicle 03 Vehicle 04	2
TYPE4	Vehicle 03 Vehicle 04 Vehicle 05	3
TYPE5	Vehicle 04 Vehicle 05	2
TYPE6	Vehicle 05	1

Using expression (5.8) and data in Table 5.5, the information content for the vehicle price attributes will be:

$$\text{I(vehicle price)} = 1 - \left(\frac{1}{|6|^2}(1 + 1 + \cdots + 1)\right) = 1 - \frac{10}{36} = 0.72.$$

An analogous approach is used to calculate the information content for the remaining vehicle attributes. The results are shown in Table 5.6. The information content will be valuable input to help identify the relative importance weight of each attribute, which is described in step 5.

Step 5: *Determine the importance (weight) of each attribute*

Expression (5.12) is a normalization equation used to identify the information significance (weight) of each attribute.

$$w(c_j) = \frac{\mathrm{I}(c_j)}{\sum_{j=1}^{n} \mathrm{I}(c_j)} \tag{5.12}$$

where aggregated weight values meet the condition $\sum_{j=1}^{n} w_j = 1$.

Table 5.6 Information Content and Importance for each sustainability attribute

Category	Attributes	Information content	Weight
Vehicle characteristics	Vehicle price	0.72	0.160
	Travelling speed range	0	0.000
	Safety features	0.78	0.173
Pollution emissions	CO_2 emissions rate	0.56	0.124
	Noise pollution rate	0.61	0.135
Policies and regulations	Compliance with government regulations	0.28	0.062
	Governments subsidies/incentives	0.28	0.062
Resources	Alternative fuel	0	0.000
	Energy consumption rate	0.78	0.173
Infrastructure	Availability of fuels	0	0.000
	Availability of maintenance services	0.5	0.111

The cumulative information content of all attributes is equal to $\sum_{j=1}^{n} \mathrm{I}(c_j) = 4.51$. The information content for vehicle price attributes is 0.72. Then the normalized weight for vehicle price attribute is $w(\text{vehicle price}) = \frac{0.72}{4.51} = 0.16$. The calculated weights of all attributes are shown in Table 5.6. For some attributes, the weight is equal to zero. According to the original Rough Set approach these attributes do not provide useful information in distinguishing the sustainability performance of different vehicles, they are excluded from subsequent analyses.

Step 6: *Determine the ideal vehicle/solution*

The most 'ideal' vehicle F^* is defined by selecting the maximum value for the attributes using expression (5.13).

$$F^+ = \{v_1^+, \ldots, v_n^+\} = \{(\max_i v_{ij})\} \tag{5.13}$$

Using expressions (5.13), we arrive at: $F^* = \{1, 1, 1, 1, 1, 1, 1, 1\}$.

Step 7: *Calculate the group utility S_i and the maximal regret Q_i*

The values of S_i and Q_i are calculated based on the expression (5.4) and (5.5). For the vehicle price attribute of vehicle 01, the distance measure is calculated as $w_{\text{Price}} d(v_{01\text{Price}}, v^*_{\text{Price}}) = 0.160^*(|0 - 1|) = 0.160$. The results for other attributes are 0, 0, 0, 0, 0, 0, and 0.087 respectively. The value of S_i for vehicle 01 is the sum of the above values, which will be equal to 0.248. The value of Q_i for vehicle 01 is the max of above values, i.e. 0.160.

Step 8: *Compute the index values (R_i)*

R_i is a compromise solution for a vehicle which is the highest ranked when considering the maximum group utility and the individual regret jointly. We set parameter v equal to 0.5 implying that the weights on the strategy of maximum group utility would be equal the weight of the individual regret. Then, we get $S^+ = \min_i S_i = 0.248, S^- = \max_i S_i = 0.840, Q^+ = \min_i Q_i = 0.110$, and $Q^- = \max_i Q_i = 0.173$. The value of R_1 for vehicle 01 would be $R_i = v(S_i - S^+)/(S^- - S^+) + (1 - v)(Q_i - Q^+)/(Q^- - Q^+) = 0.5^*(0.248 - 0.248)/(0.840 - 0.248) + 0.5^*(0.160 - 0.110)/(0.1720.110) = 0.395$. The values of S_i, Q_i, and R_i for other vehicles are shown in Table 5.7.

The compromise solutions for vehicles, which are ranked as better by the measure R_i, where smaller values are better, must satisfy the C1 and C2 conditions. For the acceptable advantage condition (C1), we have $R_3 - R_2 = 0.190 \geq 0.167$ where $R_2 = 0.050$ and $R_5 = 0.240$ and $\frac{1}{m} = \frac{1}{6} = 0.167$ shown in the Table 5.7. For the acceptable stability in decision making condition (C2), vehicles F_2 is the compromise solution.

Table 5.7 The index values for each vehicle type

Vehicle type	S_i	Ranking	Q_i	Ranking	R_i	Ranking
Vehicle 01	0.248	1	0.160	5	0.395	5
Vehicle 02	0.308	2	0.110	1	0.050	1
Vehicle 03	0.522	3	0.111	2	0.240	2
Vehicle 04	0.577	4	0.111	2	0.286	3
Vehicle 05	0.596	5	0.111	2	0.302	4
Vehicle 06	0.840	6	0.173	6	1.000	6

Step 9: *Compute the dominance probability*

VIKOR can rank the transportation vehicles, but it cannot determine the dominance probability value for each vehicle when compared to other vehicles. We introduce this important extension to the method at this time. The VIKOR methodology is enhanced since the initial data is based on decision makers' subjective judgment, the ranking result contains some probability degrees. The dominance probability degree is now determined by establishing a dominance matrix. First Definition 5.3 is introduced to help us construct the dominance matrix.

Definition 5.3 Let $x = \{x_1, x_2, \ldots, x_n\}$ and $y = \{y_1, y_2, \ldots, y_n\}$ be a transportation vehicle decision sequence consisting of the various attributes. Then the dominance probability degree of two alternative vehicles based on the VIKOR theory is obtained from expression (5.14).

$$P(x \succ y) = \begin{cases} 1 & S_x \geq S_y, Q_x \geq Q_y \\ \frac{1}{2} + \frac{1/n(S_x - S_y) + Q_x - Q_y}{1/n|S_x - S_y| + |Q_x - Q_y|} & other \\ 0 & S_x \leq S_y, Q_x \leq Q_y \end{cases} \tag{5.14}$$

where the expression "$p(x \succ y)$" represents the probability that transportation vehicle x is better than transportation vehicle y. S_x and S_y represent the maximum group utility in VIKOR for transportation vehicles x and y, respectively [see expression (5.4)]. Q_x and Q_y represent the greatest individual regret in VIKOR for transportation vehicles x and y, respectively [see expression (5.5)]. According to the dominance probability degree, the dominance probability matrix is developed using expression (5.15):

$$P_{n \times n} = p(x_j \geq x_k)_{n \times n} \tag{5.15}$$

Then the probability measure that vehicle 01 is better than vehicle 02 is $p(F_{02} \succ F_{01}) = \frac{1/6(0.248-0.308)+(0.160-0.110)}{1/6(0.308-0.248)+(0.160-0.110)} = 58.9\,\%$. The complete dominance matrix is show in Table 5.8.

Thus, with a score of 0.050 for the relative closeness, vehicle 02 is the most preferred transportation vehicle among all vehicles in the original set. Vehicle 02

Table 5.8 The dominance probability matrix

Vehicles	Vehicle 01 (%)	Vehicle 02 (%)	Vehicle 03 (%)	Vehicle 04 (%)	Vehicle 05 (%)	Vehicle 06 (%)
Vehicle 01	50.0	58.9	100.0	100.0	100.0	100.0
Vehicle 02	41.1	50.0	100.0	100.0	100.0	100.0
Vehicle 03	0.0	0.0	50.0	100.0	100.0	100.0
Vehicle 04	0.0	0.0	0.0	50.0	100.0	100.0
Vehicle 05	0.0	0.0	0.0	0.0	50.0	100.0
Vehicle 06	0.0	0.0	0.0	0.0	0.0	50.0

has a 41.1 % probability that it is better than the fifth preferred alternative, vehicle 01. The relative closeness rank with the index values (R_i) of vehicles are:

$$F_{02} \underset{100\%}{\succ} F_{03} \underset{100\%}{\succ} F_{04} \underset{100\%}{\succ} F_{05} \underset{0\%}{\succ} F_{01} \underset{100\%}{\succ} F_{06}$$

where the expression "$F_{02} \underset{100\%}{\succ} F_{03}$" represents the 100 % probability that transportation vehicle 02 is better than transportation vehicle 03. $F_{02} \succ F_{03}$ means that vehicle 02 is better than vehicle 03 according the relative closeness rank; 100 % means that vehicle 02 is 100 % likely to be better than vehicle 03 (a probability degree).

A general rank for vehicles with the index values (R_i) from the VIKOR method now exist. Also pairwise comparisons with a probability value (degree) exist. The probability degree can be used evaluate the quality of the VIKOR method rank. From the dominance probability matrix, vehicle 02 has a 41.1 % percent probability of being better than vehicle types 01. But from Table 5.7, vehicle 01 is ranked lower, using the R_i value, than vehicles 02. Additionally, we can also adjust ranks by considering dominance probability degrees for vehicles with more than 50 % dominance. In this situation, vehicle 01 is ranked first.

$$F_{01} \underset{100\%}{\succ} F_{02} \underset{100\%}{\succ} F_{03} \underset{100\%}{\succ} F_{04} \underset{100\%}{\succ} F_{05} \underset{100\%}{\succ} F_{06}$$

The reason for different results produced by the VIKOR distance measure and the dominance probability degree is that the distance measure calculates the relationship with the ideal vehicle, while the dominance probability degree measures the relationship between two vehicles in a pairwise comparison.

5.5 Conclusions

Given the critical significance of the environmental burdens of transportation activities, the need for the development of decision support tools for evaluation and selection of environmentally conscious transportation fleets is evident. This chapter introduced a novel 9-step methodology based on the integration of Rough Set theory and the VIKOR method. These two approaches allow for consideration of intangibility and ambiguity from expert judgment amongst the attributes and help reduce the number of most pertinent factors and attributes to consider. To help provide an analysis of the reliability of the VIKOR ranking results a new dominance probability degree (valuation) approach was introduced.

Although the methodology can prove valuable for evaluation of the environmental sustainability of transportation fleets by organizations, certain limitations do exist. One of the primary limitations of the modeling effort in this chapter is that we have introduced a conceptual illustrative example, rather than a real world application. There are nuances in the development and application of the methodology that can be determined through a real world application. Practical questions pertaining to the validity and accuracy of these decisions would need to be investigated.

This chapter provided a powerful tool for researchers and practitioners for complex multi-criteria transportation vehicle fleet decision making, whether it is for sustainability or business purposes.

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