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Development of a performance evaluation tool for end-of-life vehicle management system implementation using the analytic hierarchy process

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Abstract

The management of end-of-life vehicles (ELVs) conserves natural resources, provides economic benefits, and reduces water, air, and soil pollution. In an effort to adequately manage flow of ELVs, modern infrastructure is considered a prerequisite. Thus, development of an effective performance evaluation tool for monitoring and continuous improvement of ELV management systems is strongly desired. In this paper, a performance evaluation tool is proposed for ELV management system implementation, based on the analytic hierarchy process. A real-life case study in Malaysia was conducted in order to demonstrate the potential and applicability of the presented methodology. The scores of eight key success factors in establishing an ELV management system (i.e., management responsibility, performance management, capacity management, resource management, stakeholders' responsibility, education and awareness, improvement and enforcement, and cost management) are presented. The overall score of the ELV management system implementation in Malaysia is equal to 2.13. Therefore, its performance level is average. The presented multi-criteria decision analysis tool can be of assistance not only to stakeholders in the Malaysian ELV management system, but also to vehicle recycling managers from other countries in order to monitor and continuously improve their ELV management systems.

Keywords

End-of-life vehicles, Malaysia, management, decision making, analytic hierarchy process, performance evaluation

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Introduction

Waste from end-of-life vehicles (ELVs) is an issue of worldwide concern, because of its rapidly increasing quantity, the special composition of hazardous substances (Simic, 2016a; Stagner et al., 2013), and legislative pressures (Cucchiella et al., 2016; Wilts et al., 2011). Moreover, ELVs are the single largest hazardous waste category from households. The management of ELVs is currently one of the most important ecological topics (Cossu and Lai, 2015; Fiore et al., 2012; Simic and Dimitrijevic, 2015). Intensive work on the ELV management problem is necessary in order to more successfully tackle this fast-growing environmental challenge. However, in most developing countries ELVs have already caused serious environmental problems due to inadequately treated batteries and uncollected rare metals (Simic, 2016b; Wang and Chen, 2012).

In Malaysia, which belongs to the group of developing countries (Zailani et al., 2017), ELVs are not properly managed. Not only are aged vehicles still being used on the road regardless of their negative effect on the environment, but the number of unused vehicles left untreated near the roadside, in car workshops, and at parking lots keeps growing. Though businesses for used automotive parts and components exist, they do not cater for the needs of managing the increasing number of untreated ELVs in Malaysia, the number of which is increasing exponentially (Raja Ghazilla et al., 2015), as reflected by the increasing number of produced and registered vehicles every year (Raja Mamat et al., 2016). The emergence of excessive water, air, and soil pollution has resulted in more attention being given to the ELV management problem in the

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latest Malaysian national automotive policy (NAP), introduced in January 2014 (Ministry of International Trade and Industry, 2014). Moreover, environmentally sound management of ELVs in Malaysia has been set as a top priority issue.

Over the past years, a number of research works have been undertaken to solve various issues of the ELV management problem by using different multi-criteria decision making methods. Vinodh and Jayakrishna (2013) applied the analytic hierarchy process (AHP) for weighting criteria and VIKOR for selecting the best end-of-life product remanufacturing process for an Indian organization. Abdulrahman et al. (2014) used the AHP method to assess remanufacturing practices in Chinese auto parts companies. Ahmed et al. (2014) suggested that more research on sustainable ELV management in Malaysia is needed. Ziout et al. (2014) implemented AHP in the newly developed PESTEL (political, economic, social, technological, environmental, and legal) decision making framework for selecting the most sustainable end-of-life product recovery option. Xia et al. (2015) used the interval DEMATEL method to investigate internal barriers for Chinese companies that remanufacture parts from ELVs. Ahmed et al. (2016) integrated DEMATEL, extent analysis, and fuzzy AHP methods to evaluate different alternatives for processing ELVs. Kannan et al. (2016) used the fuzzy AHP method to evaluate barriers for remanufacturing parts from ELVs. Pourjavad and Mayorga (2016) coupled the fuzzy AHP and fuzzy TOPSIS methods to rank seven ELV management strategies. Schmid et al. (2016) compared three scenarios for dismantling and shredding operations of ELVs in France using the PROMETHEE method. Zhou et al. (2016) applied the fuzzy VIKOR method to rank numerous ELV recycling service providers. Tian and Chen (2016) used the fuzzy AHP method to rank five different scenarios for manual dismantling of ELVs. Gan and Luo (2017) used the fuzzy DEMATEL method to identify critical factors influencing the recycling rate of ELVs in China. Tian et al. (2017) integrated the fuzzy AHP and fuzzy gray TOPSIS methods to evaluate operation patterns for the automotive components remanufacturing industry in China. Zhang and Chen (2018) ranked four alternatives for sustainable ELV disassembly in China using the AHP method. Recently, several reviews of the literature related to ELV management have been published (Cin and Kusakci, 2017; Cossu and Lai, 2015; Gan and He, 2014; Go et al., 2011; Lashlem et al., 2013; Mayyas et al., 2012). For instance, Sakai et al. (2014) provided a comparative analysis of ELV recycling systems in order to evaluate the characteristics and effectiveness of legislative systems in several countries and regions.

From the review of previous literature it is evident that a number of systems analysis methods have been developed for solving various ELV management problems. However, none of the previous studies provided an effective performance evaluation tool for monitoring and continuous improvement of ELV management systems. This research presents the first attempt to develop a multi-criteria decision analysis tool for ELV management system implementation. The proposed AHP-based tool will then be applied to a real-life case study to demonstrate its potential and applicability as well as to provide strategic information for policy makers, authorities, and vehicle recycling industry practitioners.

Research methodology

Multi-criteria decision making is becoming more crucial. This is in line with the emerging of complex problems that require a quick and effective decision. AHP is one of the approaches used widely by practitioners and academic researchers (Achillas et al., 2013; Goulart Coelho et al., 2017; Kling et al., 2016; Tot et al., 2016). It can simplify a complex problem into hierarchies, namely the goal, the criteria, and the alternative; thus the problem can be solved systematically (Saaty, 1977, 1980). The available alternatives are evaluated based on the specified criteria by means of pairwise comparison. The relative importance of the criteria is obtained from decision makers who depend on their knowledge and experience in a certain area or field of interest. In the evaluation process, the alternatives are ranked according to their relative importance, locally and globally.

The ranking is specified based on the weightage of the criteria. Other than for ranking purposes, the weightage can also be used to calculate the performance score. Through performance evaluation activity, current performance score and performance level are identified. Results of the performance evaluation activity can guide evaluators and practitioners in deciding which item should be given priority and attention for better implementation.

AHP is employed in this research. Firstly, the AHP goal is set to determine the strategy priorities for ELV management system implementation in Malaysia. The criteria that contribute to the strategy priorities were obtained from a set of important factors and items, as listed in Table 1. These items and factors were formulated from a series of methods which were conducted by Raja Mamat et al. (2016): a thorough WOT analysis of current ELV practices in Malaysia, a comprehensive literature review of the work on ELV management, and the factor analysis method (which was applied to assign the items to the key factors). They represent the factors and items that are important in implementing an ELV management system in Malaysia. By assigning the factors and items to the criteria and sub-criteria of AHP, respectively, their priority can be determined. The AHP diagram is depicted in Figure 1.

It is observed from Figure 1 that the AHP diagram for this study does not include AHP alternatives, because this study's goal is to identify the priority of factors and items. Studies conducted previously by Talib et al. (2011), Lin and Harris (2013), and Nikou and Mezei (2013) employed the similar methodological approach. For example, Nikou and Mezei (2013) did not include alternatives when they used AHP to select the most preferred mobile service category and the most important factors influencing the adoption of mobile services based on consumers' preferences.

From the identified criteria and sub-criteria, an AHP questionnaire is designed for the purpose of data collection. The AHP questionnaire requires respondents to rate their perceived level of

Table 1. Factors, items, and strategies.

Factor	Item	Initiative/strategy
Management responsibility	Objectives	Determine the objectives of the implementation of the ELV management system
	ELV policy	Establish a national ELV policy
	Strategic plan	Establish a national strategic plan or roadmap toward achieving the objectives and targets
	Targets	Determine specific targets to be achieved within a specified period of time (for example, recycling rate and waste disposal rate)
	Code of practice	Establish national code of practice for ELV management
	Regulation	Establish a regulation or legislation related to ELV management
Performance management	Tax exemption	Offer a tax exemption for facilities or stakeholders who meet the specified target within the specified period of time
	Incentive/ rebate	Offer an incentive or rebate scheme for ELV owners who send their vehicles for deregistration and ELV treatment
	Periodic monitoring	Monitor the performance of ELV processes and management by means of periodic report and review
	Continuous improvement	Establish improvement plan to improve the performance upon periodic review continuously
	Online monitoring system	Establish an online monitoring system to monitor the flow of ELV processes
	Documentation	Maintain a good documentation of records
Capacity management	Authorized treatment facilities (ATFs)	Establish the ATFs where the ELV treatment processes are centralized
	Collection centers	Establish ELV collection centers
	Inspection centers	Increase the number of inspection centers for vehicle roadworthiness inspection
	Standard operating procedure (SOP)	Establish the SOP for ELV processes (for example, ELV collection process, ELV recycling, disposal)
Resource management	Stakeholders' responsibility and authority	Define the responsibilities and authorities of the stakeholders in the ELV management system
	Stakeholders' availability and competency	Identify the availability and competency of the stakeholders in implementing ELV management system
	Infrastructure availability and capacity	Identify the availability and capacity of the infrastructure to be utilized for ELV management
	Independent management body	Establish an independent body who is responsible for managing and coordinating the ELV processes
Stakeholders' responsibility	Supplier commitment and awareness	Create supplier commitment and awareness toward environmental measures through supplier education, supplier audit, and selection of the supplier
	ISO standard	Establish ISO standards on ELV management system and its requirement
	Organization members responsibility and authority	Define the responsibilities and authorities of the organization members involved with ELVs
	Environmental management system (EMS) integration	Integrate the EMS into ELV management
	Organization commitment	Strive toward obtaining the required license/permit/certification prior to conducting ELV processes
Education and awareness	Public awareness	Provide education and awareness campaign to increase the level of knowledge and awareness of public society on the ELV processes and their importance
	Organization members training	Provide training to the organization members involved with ELVs to ensure the required knowledge and competency levels to perform their responsibilities are achieved
	Stakeholders' training	Provide training to the stakeholders to ensure the required knowledge and competency levels to perform their responsibilities are achieved
Improvement and enforcement	Deregistration enforcement	Enforce the ELV deregistration process and impose penalty for those who failed to comply to this regulation
	Penalty	Impose a penalty on the organizations that cause pollution and environmental destruction
	Research and development	Encourage and support the research and development activities on ELVs
Cost management	Budget allocation	Provide budget allocation for the development of the ELV management system
	Cost	Identify the cost required for the development of the ELV management system (for example, cost of new technology development, the cost of recycling infrastructure development, and recycling cost)

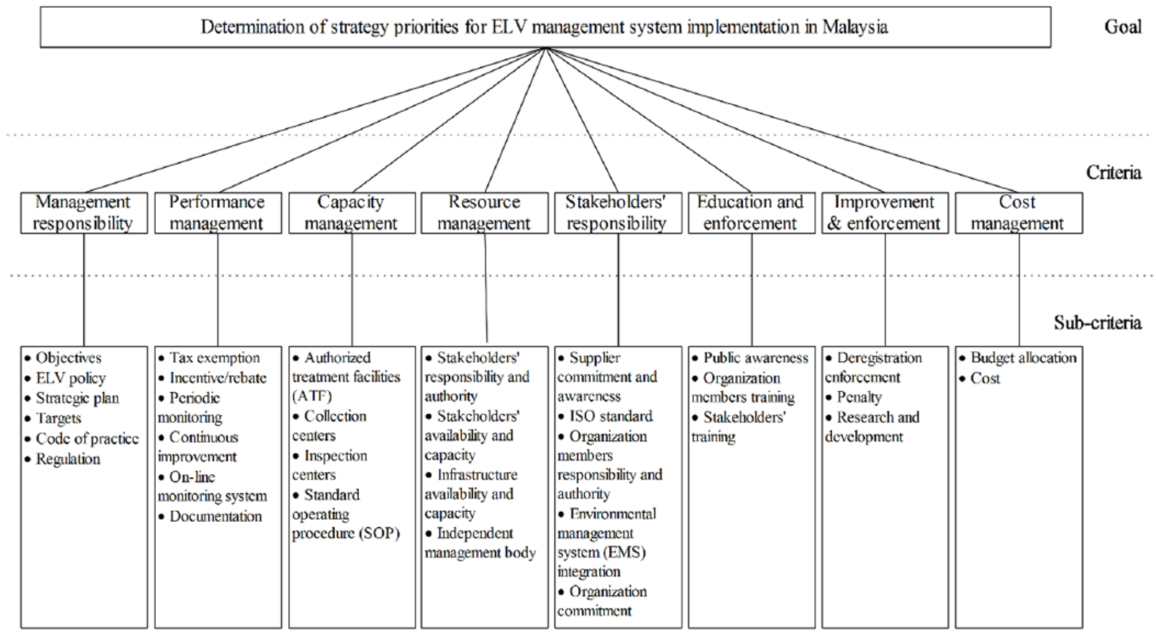

Figure 1. AHP diagram for the research.

Table 2. Fundamental scale of judgment (Saaty and Vargas, 2012).

Scale	Definition	Description
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate	Intermediate
Reciprocals of above	–	If activity *i* is assigned one of the above numbers when compared to activity *j*, then activity *j* is assigned the number's reciprocal value when compared to activity *i*

relative importance between two elements, be it between factor and factor or between item and item in a particular factor. This type of judgment is known as the pairwise comparison method (Saaty and Vargas, 2012). The pairwise comparison requires respondents to have an adequate knowledge and sufficient experience in the field of study.

In order to assist the decision maker in justifying AHP results, Saaty (1980) introduced consistency test through the determination of consistency ratio (CR). CR that meets the acceptable limit ensures a consistent judgment by the respondents. The fundamental scale used in the AHP questionnaire, which was introduced by Saaty and Vargas (2012), ranges between 1 and 9. Definition of fundamental scale of judgment is provided in Table 2. AHP requires judgment on relative importance between two elements, be it factors or items in this study. Scale 1 indicates that both elements are relatively equal in contributing to the goal. Scale 2 until scale 9 indicate that one element is relatively more important than the other, in which the bigger the number, the higher the dominance of one element over the other. On the other hand, reciprocals of these numbers indicate inverse relativity.

Upon analysis of AHP data, importance weightages of the factors and items are obtained. This weightage was used in the next step of this research, which is to calculate the performance score of ELV management system implementation in Malaysia.

Performance evaluation is an important process in ensuring a continuous improvement of the implementation. During the evaluation stage, each implementation item is rated and given an individual score. Upon calculation, factors and overall scores are obtained. These scores are indicators of the current status of performance of the implementation. Low score factors are given priority by the policy makers and authorities to focus on improvement. The evaluation process can be conducted on a regular basis to ensure the implementation performance is improved and maintained appropriately.

The steps involved in the methodology are presented in Figure 2. The first stage of the study is the critical review of literature. The

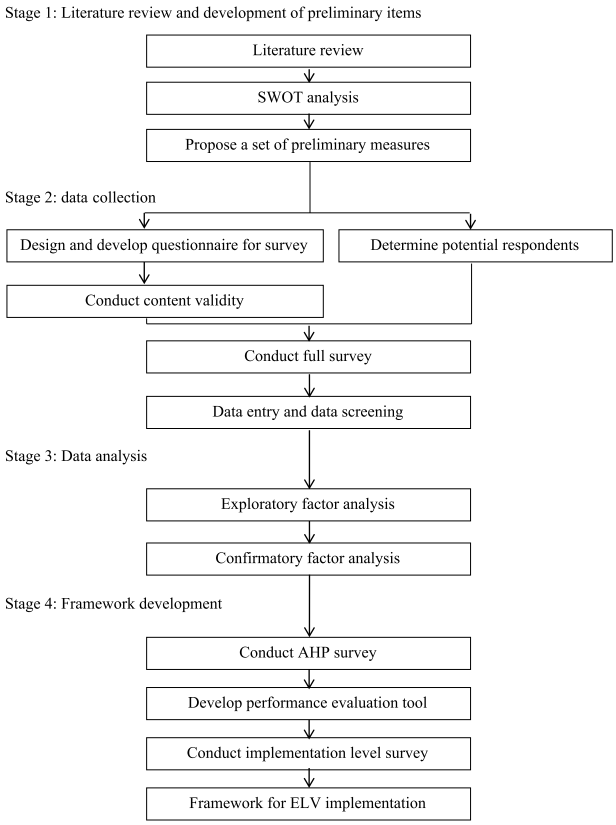

Figure 2. Steps involved in the research methodology.

literature reviews are from two main categories. The first category is literature on the concepts and theory of ELVs, which include automotive recycling, ELV management, sustainability, and reverse supply chain management. The second category relates to the research methodology which often engages in this type of research, such as questionnaire design, critical success factors, development of the framework, factor analysis, structural equation modeling (SEM), and AHP. From previous literature and SWOT analysis of current ELVs practice in Malaysia, a set of preliminary items in implementing ELVs management system is proposed.

In the second stage, for data collection, the items are used in the development of a questionnaire. A content validity test was conducted to ensure the validity of the instrument. At the same time, potential respondents were identified, which are among various stakeholders in the Malaysia ELVs management.

A pilot study was conducted by distributing the validated questionnaire to the selected respondents. Upon completing the pilot study, necessary improvement of items of the questionnaire, data collecting method, and target respondent were made. These processes did not only overcome existing problems from the pilot study but also aimed at increasing the interest of respondents, which eventually improves the response rate during the full survey. Once the questionnaire was revised and finalized, an online version of the questionnaire was developed by utilizing the Google Drive application. Subsequently, a full survey was conducted to the target respondents by manual and online questionnaire. The responses received were compiled and the data entry process was performed. Before analyzing the data, a data screening process was carried out in order to deal with missing values and outliers.

The third stage focused on the data analysis. Since the research is an exploratory research, the data was initially analyzed through the exploratory factor analysis (EFA) to check for measures subjected for deletion. Then, confirmation of the measures obtained in EFA was conducted through CFA. SEM approach was selected to perform CFA.

In the final stage, the confirmed set of items and factors were analyzed using the AHP approach in order to determine the priority ranking. From AHP, strategies in implementing the ELVs management system in Malaysia are ranked according to its importance level which provides an input to develop a framework towards its implementation.

Results and discussion

AHP results and analysis

The completed AHP questionnaire was distributed during the first part of data collection activity through email to 20 potential respondents, which comprised industry practitioners from executive to managerial levels with 5 years involvement and experience in the automotive industry. Among them, seven responses were received. Additional effort was carried out by approaching another six potential respondents personally, of which three respondents agreed to meet and answer the AHP questionnaire face-to-face. Thus, a total of 10 responses were received within 4 months of the data collection activity. However, four responses were found to have a suspicious response pattern and thus withdrawn from the data set.

Microsoft Excel 2010 was used to analyze the compiled AHP data set. Firstly, the geometric mean of the data set was calculated and then the values were used to construct pairwise comparison matrices. Finally, the priority vectors were calculated, which also represent the required importance weightage. Table 3 lists the obtained AHP results of the factors.

The importance weightage of a factor shows its priority in implementing ELV management system (Figure 3). From Figure 2 it can be identified that the most important factor is the management responsibility with 0.3352, followed by the performance management with 0.1114 and the capacity management with 0.1036. The least important factor is the improvement and enforcement with 0.0756. Additionally, the calculated consistency ratio is below than the acceptable limit, thus the pairwise judgment is consistent.

Afterwards, the same calculation method was applied to the items of each particular factor. The obtained AHP results are presented in Table 4. For the items, there are two types of importance weightage. The local importance weightage is the weightage with respect to their particular factor, while global importance weightage is the overall weightage. For this study, global importance weightage of all 33 items summed up to 1.000.

Table 3. AHP results of the factors.

Factor	Pairwise comparison of the factors	Geometric mean	Importance weightage	Rank
F1	F1–F2	3.3604	0.3352	1
	F1–F3	3.3019		
	F1–F4	3.3220		
	F1–F5	4.0933		
	F1–F6	3.2031		
	F1–F7	4.0357		
	F1–F8	3.9895		
F2	F2–F3	1.0612	0.1114	2
	F2–F4	1.0889		
	F2–F5	1.6475		
	F2–F6	1.4848		
	F2–F7	1.2745		
	F2–F8	1.0000		
F3	F3–F4	0.7937	0.1036	3
	F3–F5	1.6475		
	F3–F6	1.2009		
	F3–F7	1.4422		
	F3–F8	0.9184		
F4	F4–F5	0.9467	0.1005	4
	F4–F6	0.8849		
	F4–F7	1.0699		
	F4–F8	1.4422		
F5	F5–F6	0.8088	0.0832	7
	F5–F7	1.3480		
	F5–F8	0.9635		
F6	F6–F7	1.5399	0.0967	5
	F6–F8	0.9005		
F7	F7–F8	0.8023	0.0756	8
F8	–	–	0.0938	6

Consistency ratio: 0.0092 ($\leftarrow$0.1000 for $n \rightarrow 4$).

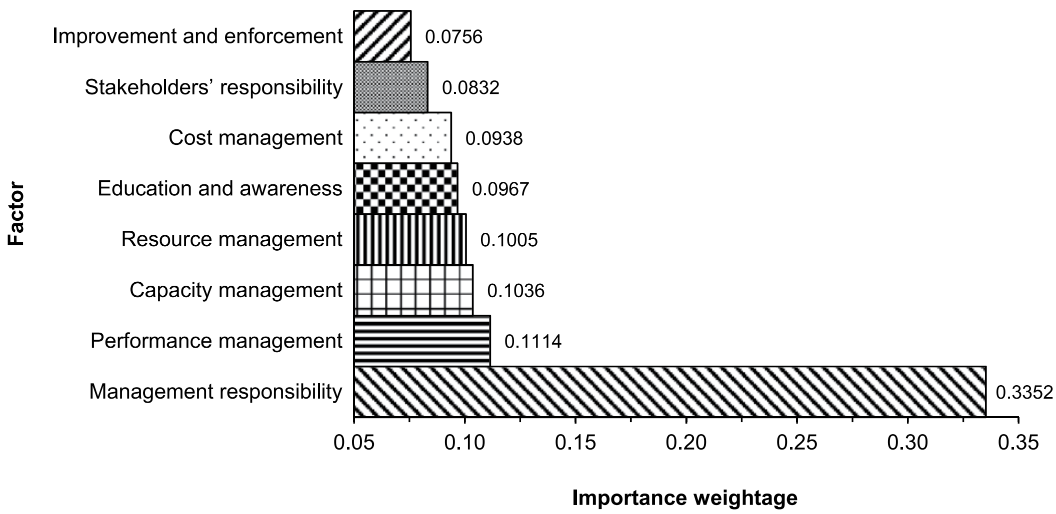

Figure 3. Priorities of the key success factors in establishing end-of-life vehicle management system.

Priority of an item is equal to its global importance weightage. The calculated priorities of 33 items are depicted in Figure 4. From Figure 4, it is evident that ELV policy is the most important item with the global importance weightage equal to 0.0724. On the other hand, tax exemption is the least important item with the lowest global importance weightage of 0.0107.

Most of the items in the first factor, namely management responsibility, show high global importance weightage. More

Table 4. AHP results of the items.

Factor	Item	Compared item	Geometric mean	Local importance weightage	Rank	Global importance weightage	Rank	Consistency ratio
F1	Objectives	ELV policy	1.1856	0.1915	2	0.0642	2	0.0094 ($\leftarrow$0.1000 for $n \rightarrow 4$)
		Strategic plan	1.0000					
		Targets	1.0428					
		Code of practice	2.2894					
		Regulation	1.1517					
	ELV policy	Strategic plan	1.1776	0.2159	1	0.0724	1	
		Targets	1.1650					
		Code of practice	3.1665					
		Regulation	1.8086					
	Strategic plan	Targets	0.8754	0.1763	4	0.0591	5	
		Code of practice	2.2894					
		Regulation	1.2139					
	Targets	Code of practice	2.8845	0.1830	3	0.0613	3	
		Regulation	0.9391					
	Code of practice	Regulation	0.3379	0.0690	6	0.0231	20	
	Regulation	–	–	0.1642	5	0.0551	6	
F2	Tax exemption	Incentive/rebate	0.9184	0.0960	6	0.0107	33	0.0096 ($\leftarrow$0.1000 for $n \rightarrow 4$)
		Periodic monitoring	0.3637					
		Cont. improvement	0.4555					
		Online monitoring system	0.7148					
		Documentation	0.5054					
	Incentive/ rebate	Periodic monitoring	0.4025	0.1171	5	0.0130	31	
		Cont. improvement	0.5774					
		Online monitoring system	0.9109					
		Documentation	0.7611					
	Periodic monitoring	Cont. improvement	1.9064	0.2662	1	0.0297	13	
		Online monitoring system	1.6984					
		Documentation	1.0379					
	Continuous improvement	Online monitoring system	1.5525	0.1977	2	0.0220	21	
		Documentation	1.2566					
	Online monitoring system	Documentation	0.6368	0.1321	4	0.0147	28	
	Documentation	–	–	0.1909	3	0.0213	22	
F3	Authorized treatment facilities	Collection centers	2.0396	0.2749	2	0.0285	14	0.0008 ($\leftarrow$0.0800 for $n = 4$)
		Inspection centers	1.1745					
		Standard operating procedure (SOP)	0.7647					
	Collection centers	Inspection centers	0.6257	0.1403	4	0.0145	29	
		SOP	0.4058					
	Inspection centers	SOP	0.5888	0.2235	3	0.0232	19	
	SOP	–	–	0.3613	1	0.0374	8	

(Continued)

Table 4. (continued)

Factor	Item	Compared item	Geometric mean	Local importance weightage	Rank	Global importance weightage	Rank	Consistency ratio
F4	Stakeholders' responsibility and authority	Stakeholders' availability and competency	0.8849	0.2366	2	0.0238	17	0.0029 (←0.0800 for $n = 4$)
		Infrastructure availability and capacity (IAC)	0.7324					
		Independent management body (IMB)	1.3719					
	Stakeholders' availability and competency	IAC	0.6355	0.2362	3	0.0237	18	
		IMB	1.2280					
	IAC	IMB	1.8860	0.3451	1	0.0347	9	
	IMB	–	–	0.1821	4	0.0183	24	
F5	Supplier commitment and awareness	ISO standard	1.8012	0.1449	5	0.0121	32	0.0046 (←0.1000 for $n \rightarrow 4$)
		Organization members responsibility and authority (OMRA)	0.5673					
		Environmental management system (EMS) integration	1.0940					
		Organization commit.	0.4724					
	ISO standard	OMRA	0.8950	0.1826	3	0.0152	27	
		EMS integration	1.1225					
		Organization commit.	0.6441					
	OMRA	EMS integration	1.1571	0.2085	2	0.0173	25	
		Organization commit.	0.6177					
	EMS integration	Organization commit.	0.5144	0.1574	4	0.0131	30	
	Organization commitment	–	–	0.3066	1	0.0255	16	
F6	Public awareness	Organization members training	1.9786	0.4388	1	0.0425	7	0.0012 (←0.0500 for $n = 3$)
		Stakeholders' training	1.3104					
	Organization members training	Stakeholders' training	0.5952	0.2141	3	0.0207	23	
	Stakeholders' training	–	–	0.3471	2	0.0335	10	
F7	Deregistration enforcement	Penalty	1.9064	0.4324	1	0.0327	12	0.0000 (←0.0500 for $n = 3$)
		Research and development (R&D)	1.2685					
	Penalty	R&D	0.6680	0.2271	3	0.0172	26	
	R&D	–	–	0.3404	2	0.0257	15	
F8	Budget allocation	Cost	0.5529	0.3560	2	0.0334	11	Not available
	Cost	–	–	0.6440	1	0.0604	4	
						1.0000		

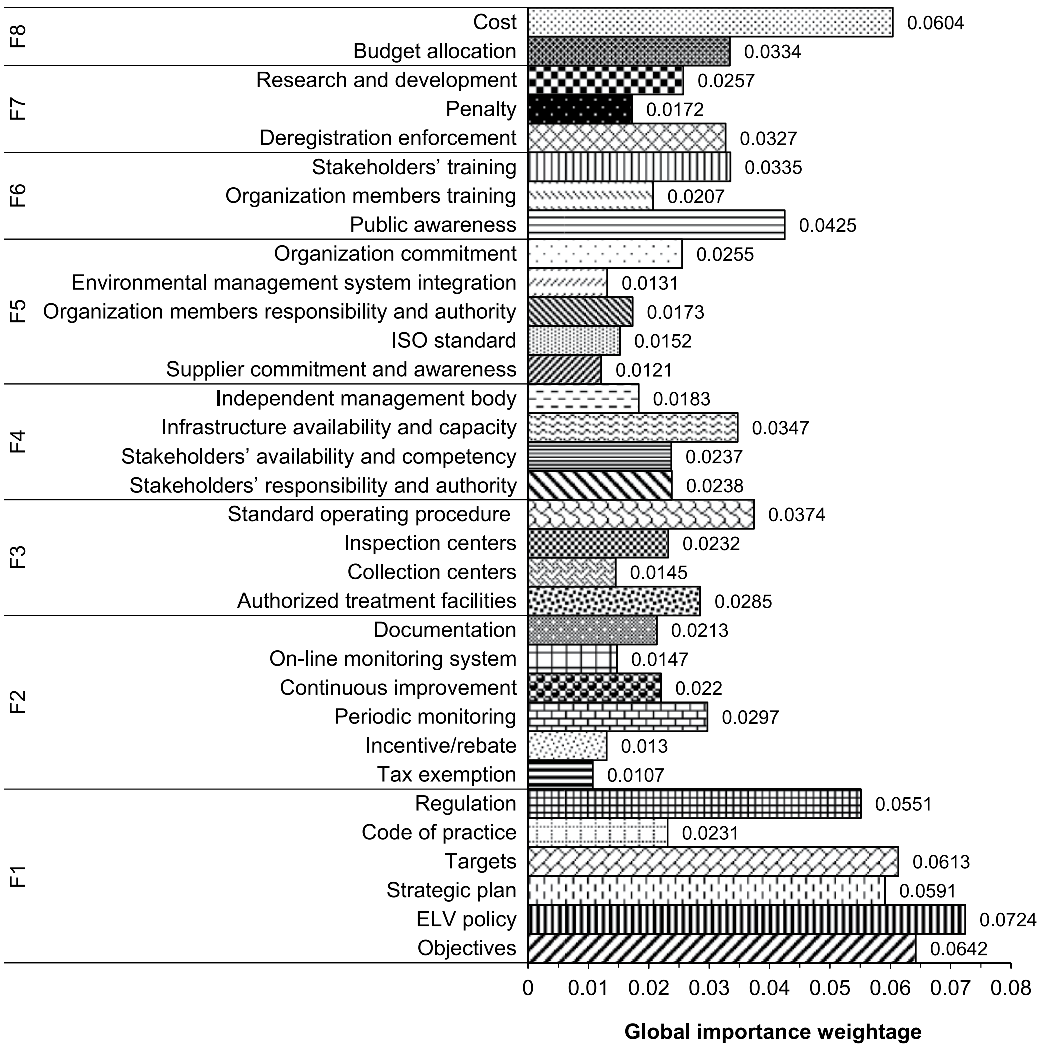

Figure 4. Priorities of the items.

detailed, the second rank item is objectives, with global importance weightage equal to 0.0642. Targets, strategic plan, and regulation get ranking numbers 3, 5, and 6 with global importance weightage equal to 0.0613, 0.0591, and 0.0551, respectively.

Performance evaluation and a tool for determining performances of ELV management systems

Upon obtaining the global importance weightage, the performance score of each factor and the overall score of the ELV management system implementation of a certain period of time can be calculated. The performance scores are very important particularly for the enforcement bodies such as The Ministry of International Trade and Industry (MITI) of Malaysia and the Malaysia Automotive Institute (MAI) in identifying current performance of ELV management system implementation. By observing an individual factor's score, they are able to develop better improvement plans by giving priority to the lowest performance score factor.

As for the preliminary performance score, the score of each item is obtained from industry evaluators during the second part of the data collection activity. Another expert group comprising industrial practitioners and academicians was approached. A set of questionnaires was emailed to the respondents, which required them to rate the items' score based on the following scale: 0 = not available, 1 = poor, 2 = bad, 3 = average, 4 = good, and 5 = excellent.

The items' scores given by the experts were compiled and mean scores calculated accordingly (Table 5). Then, the individual factor score is obtained by the sum of the product of the mean item score and the global importance weightage of the items in each factor, divided by the sum of the global importance weightage of the items in each factor (Amrina and Vilsi, 2015; Amrina and Yusof, 2013). The importance weightages, mean and weighted scores of 33 items, as well as scores of eight key success factors are shown in Table 5. Subsequently, the overall score of the ELV management system implementation is equal to 2.13. It is obtained by summing the weighted scores of all 33 items.

Based on the factor score values (Table 5), the performance level of each factor is determined according to the general

Table 5. The global importance weightages, mean and weighted scores of the items, and calculated total scores of the factors.

Factor	Item	Global importance weightage	Mean item score	Weighted item score	Total factor score
F1	Objectives	0.0642	2.57	0.1650	2.46
	ELV policy	0.0724	2.29	0.1658	
	Strategic plan	0.0591	3.14	0.1856	
	Targets	0.0613	2.29	0.1404	
	Code of practice	0.0231	1.86	0.0430	
	Regulation	0.0551	2.29	0.1262	
F2	Tax exemption	0.0107	1.71	0.0183	1.89
	Incentive/rebate	0.0130	1.86	0.0242	
	Periodic monitoring	0.0297	1.86	0.0552	
	Continuous improvement	0.0220	1.86	0.0409	
	Online monitoring system	0.0147	1.57	0.0231	
	Documentation	0.0213	2.29	0.0488	
F3	Authorized treatment facilities	0.0285	1.86	0.0530	1.90
	Collection centers	0.0145	1.57	0.0228	
	Inspection centers	0.0232	2.00	0.0464	
	Standard operating procedure	0.0374	2.00	0.0748	
F4	Stakeholders' responsibility and authority	0.0238	2.29	0.0545	1.98
	Stakeholders' availability and competency	0.0237	2.14	0.0507	
	Infrastructure availability and capacity	0.0347	1.71	0.0593	
	Independent management body	0.0183	1.86	0.0340	
F5	Supplier commitment and awareness	0.0121	1.71	0.0207	1.92
	ISO standard	0.0152	2.14	0.0325	
	Organization members responsibility and auth.	0.0173	2.00	0.0346	
	Environmental management system integration	0.0131	1.57	0.0206	
	Organization commitment	0.0255	2.00	0.0510	
F6	Public awareness	0.0424	2.00	0.0848	1.90
	Organization members training	0.0207	2.00	0.0414	
	Stakeholders training	0.0335	1.71	0.0573	
F7	Deregistration enforcement	0.0327	1.71	0.0559	2.05
	Penalty	0.0172	2.14	0.0368	
	Research and development	0.0257	2.43	0.0625	
F8	Budget allocation	0.0334	1.86	0.0621	2.14
	Cost	0.0604	2.29	0.1383	

Table 6. Specification of performance levels.

Score range	Performance level
0.00	Not available
0.01–1.00	Poor
1.01–2.00	Bad
2.01–3.00	Average
3.01–4.00	Good
4.01–5.00	Excellent

performance levels listed in Table 6. A summary of the results of the performance evaluation is shown in Table 7.

The overall performance evaluation score and performance level obtained in this study show that the implementation of ELV management system in Malaysia is currently at an average level, in which the factor performance evaluation score can be observed to determine specific factor implementation performance. Three factors, namely management responsibility, improvement and enforcement, and cost management have resulting average performance levels, while the remaining five factors, i.e., performance management, capacity management, resource management, stakeholders' responsibility, and education and awareness, have obtained bad scores.

The scores obtained are in line with current status of ELV management in Malaysia, which is still in its infancy stage. ELV policy is yet to be established, the automotive recycling business is unregulated, and knowledge and awareness on management of ELVs and its importance is still lacking. Thus, the Malaysian policy makers and authorities should use this performance evaluation result as a basis to initiate ELV management system implementation. By focusing on the low score factors, an action plan should be planned accordingly.

To continuously improve the ELV management system implementation, regular evaluation is required. Upon evaluation, the enforcement bodies may focus their attention to improve on a particular factor or specific strategy that recorded the lowest score. In order to ease the performance evaluation process, an evaluation tool was developed with Microsoft Excel 2013. Its flowchart is shown in Figure 5.

Table 7. Summary results of the performance evaluation.

Factor	Performance score	Performance level
F1	2.46	Average
F2	1.89	Bad
F3	1.90	Bad
F4	1.98	Bad
F5	1.92	Bad
F6	1.90	Bad
F7	2.05	Average
F8	2.14	Average
ELV management system implementation	2.13	Average

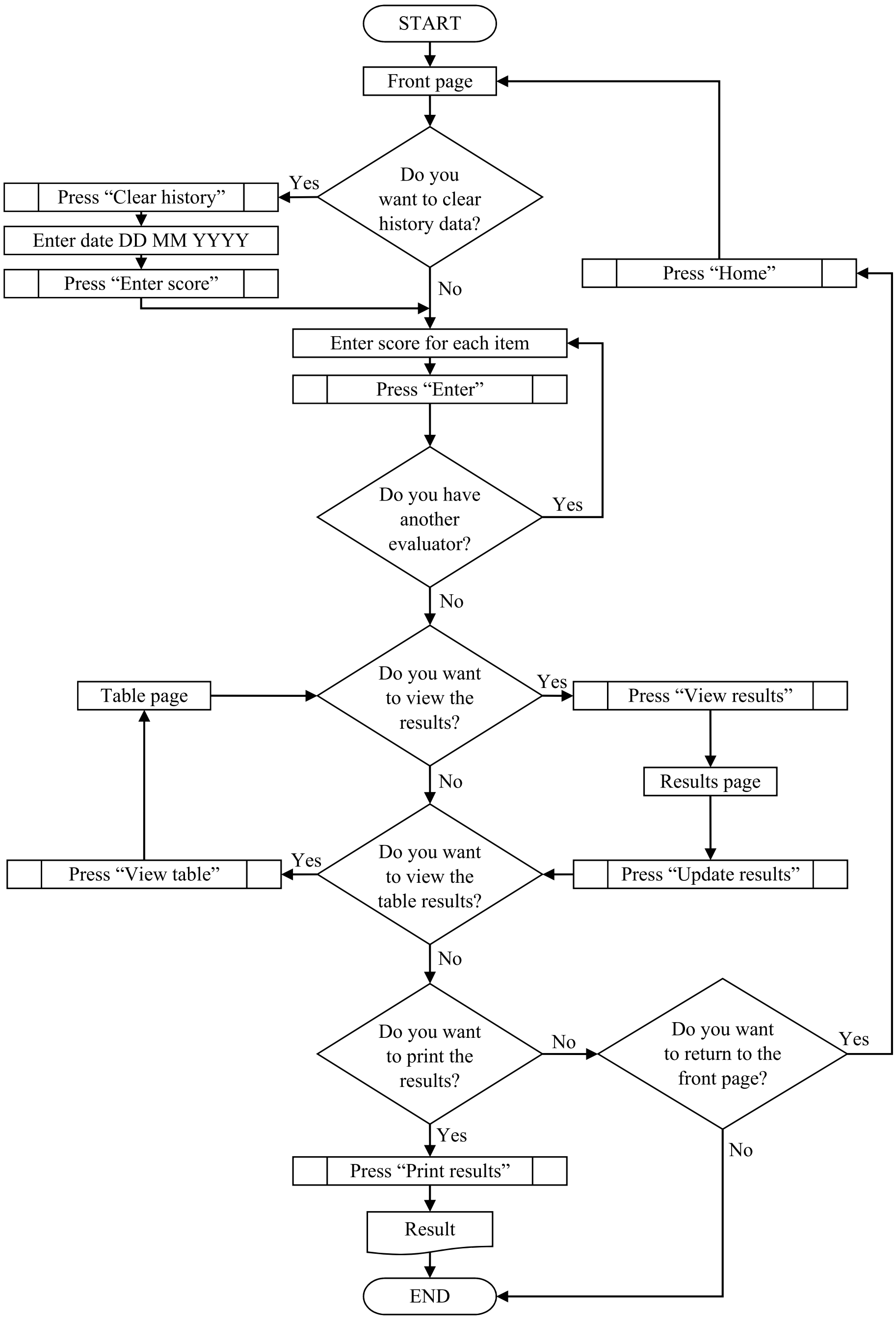

Figure 5. Process flow of the performance evaluation system.

The proposed tool enables the enforcement bodies to enter the individual score of each strategy implemented on a timely basis. By just one click, they can directly obtain the scores of all factors and overall score of the ELV management system implementation. The presented tool for determining performances of ELV management systems enables the performance evaluation process to be filled up by numerous evaluators, in which mean scores are calculated first. Once all the scores are stored, the users can choose either to view the calculated results in table form or graphic form, by just clicking on either "View table" or "View results," respectively. Lastly, the users can print both forms of results by pressing "Print results" button. If the users are willing to start a new evaluation process, they may want to clear the previous data by pressing "Clear history" button. Based on the obtained results, the evaluators may decide on which strategy to focus on and the next action plan to be implemented to ensure the successful implementation of the ELV management system in Malaysia. Among the special features of this tool are its ability to gather evaluation from more than one evaluator at one time, its ability to clear previous history data to begin a new evaluation activity, and its ability to display the results in either visual or table forms.

The merits of the presented real-life case study of Malaysia are manifold. First, the potential and applicability of the proposed methodology are illustrated. Second, the obtained numerical results are useful for monitoring and continuous improvement of ELV management systems, thus validating the presented methodology. Third, the results can provide strategic information for policy makers, authorities, and vehicle recycling industry practitioners.

Conclusions

In this paper, a performance evaluation tool for ELV management system implementation is presented. The AHP, one of the most popular multi-criteria decision making methods, is used to identify the priority ranking of the eight key success factors and 33 underlying items.

The set of items and factors ranked according to their importance level is first introduced in a Malaysian context. The ranking provides valuable insight to policy makers, authorities, and vehicle recycling industry practitioners on relative importance between each item and factor. Subsequently, the importance weightage obtained through AHP is used to develop a performance evaluation tool for ELV management system implementation in Malaysia. Current implementation is evaluated by using this tool. Performance score and level obtained indicate how successful the implementation is. The scores of eight key success factors are presented. The overall score of the ELV management system implementation in Malaysia is equal to 2.13. Therefore, its performance level is average. Regular evaluation activity must be performed to ensure continuous improvement of the ELV management system in Malaysia. Items or factors with low performance score are the ones that should be given more attention and priority by the relevant decision makers.

The developed AHP-based tool can be of assistance not only to stakeholders in Malaysian ELV management systems, but also to vehicle recycling managers from other countries in order to monitor and continuously improve their ELV management systems. It is applicable across the vehicle recycling industry that processes dozens of millions of ELVs every year. However, the existing literature lacks documentation of present industry practices in the area of ELV management. In fact, the lack of documented practices in this field is one of the major drawbacks of previous papers. Hence, the proposed multi-criteria decision analysis tool should be implemented in other countries in future studies.

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References

Abdulrahman MD-A, Subramanian N, Liu C, et al. (2014) Viability of remanufacturing practice: a strategic decision making framework for Chinese auto-parts companies. *Journal of Cleaner Production* 105: 311–323.

Achillas C, Moussiopoulos N, Karagiannidis A, et al. (2013) The use of multi-criteria decision analysis to tackle waste management problems: a literature review. *Waste Management & Research* 31: 920–924.

Ahmed S, Ahmed S, Shumon MRH, et al. (2014) End-of-life vehicles (ELVs) management and future transformation in Malaysia. *Journal of Applied Science and Agriculture* 9: 227–237.

Ahmed S, Ahmed S, Shumon MRH, et al. (2016) Prioritizing strategies for sustainable end-of-life vehicle management using combinatorial multi-criteria decision making method. *International Journal of Fuzzy Systems* 18: 448–462.

Amrina E and Vilsi AL (2015) Key performance indicators for sustainable manufacturing evaluation in cement industry. *Procedia CIRP* 26: 19–23.

Amrina E and Yusof SM (2013) An AHP-based model for sustainable manufacturing performance evaluation in automotive industry. In: *Proceedings of the 12th international symposium on the analytic hierarchy process*, Kuala Lumpur, Malaysia, 23–26 June 2013.

Cin E and Kusakci AO (2017) A Literature Survey on Reverse Logistics of End of Life Vehicles. *Southeast Europe Journal of Soft Computing* 6: 32–39.

Cossu R and Lai T (2015) Automotive shredder residue (ASR) management: an overview. *Waste Management* 45: 143–151.

Cucchiella F, D'Adamo I, Rosa P, et al. (2016) Scrap automotive electronics: a mini-review of current management practices. *Waste Management & Research* 34: 3–10.

Fiore S, Ruffino B and Zanetti MC (2012) Automobile shredder residues in Italy: characterization and valorization opportunities. *Waste Management* 32: 1548–1559.

Gan J and Luo L (2017) Using DEMATEL and intuitionistic fuzzy sets to identify critical factors influencing the recycling rate of end-of-life vehicles in China. *Sustainability* 9: 1873.

Gan JW and He ZG (2014) Literature review and prospect on the end-of-life vehicles reverse logistics. *Advanced Materials Research* 878: 66–74.

Go TF, Wahab DA, Rahman MNA, et al. (2011) Disassemblability of end-of-life vehicle: a critical review of evaluation methods. *Journal of Cleaner Production* 19: 1536–1546.

Goulart Coelho LM, Lange LC and Coelho HM (2017) Multi-criteria decision making to support waste management: a critical review of current practices and methods. *Waste Management & Research* 35: 3–28.

Kannan G, Shankar KM and Kannan D (2016) Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production – a study in an Indian scenario. *Journal of Cleaner Production* 114: 199–213.

Kling M, Seyring N and Tzanova P (2016) Assessment of economic instruments for countries with low municipal waste management performance: an approach based on the analytic hierarchy process. *Waste Management & Research* 34: 912–922.

Lashlem AA, Wahab DA, Abdullah S, et al. (2013) A review on end-of-life vehicle design process and management. *Journal of Applied Sciences* 13: 654–662.

Lin CS and Harris SL (2013) A unified framework for the prioritization of organ transplant patients: Analytic hierarchy process, sensitivity and multifactor robustness study. *Journal of Multi-Criteria Decision Analysis* 20: 157–172.

Mayyas A, Qattawi A, Omar M, et al. (2012) Design for sustainability in automotive industry: a comprehensive review. *Renewable and Sustainable Energy Reviews* 16: 1845–1862.

Ministry of International Trade and Industry (2014) National automotive policy (NAP) 2014. Available at: www.maa.org.my/pdf/NAP_2014_policy.pdf (accessed 1 April 2018).

Nikou S and Mezei J (2013) Evaluation of mobile services and substantial adoption factors with analytic hierarchy process (AHP). *Telecommunications Policy* 37: 915–929.

Pourjavad E and Mayorga RV (2016) A hybrid approach integrating AHP and TOPSIS for sustainable end-of-life vehicle strategy evaluation under fuzzy environment. *WSEAS Transactions on Circuits and Systems* 15: 216–223.

Raja Ghazilla RA, Sakundarini N, Taha Z, et al. (2015) Design for environment and design for disassembly practices in Malaysia: a practitioner's perspectives. *Journal of Cleaner Production* 108: 331–342.

Raja Mamat TNA, Mat Saman MZ, Sharif S, et al. (2016) Key success factors in establishing end-of-life vehicle management system: a primer for Malaysia. *Journal of Cleaner Production* 135: 1289–1297.

Saaty TL (1977) A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology* 15: 234–281.

Saaty TL (1980) *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. New York: McGraw-Hill.

Saaty TL and Vargas GL (2012) *Models, Methods, Concepts, and Applications of the Analytic Hierarchy Process*. 2nd ed. New York: Springer Science & Business Media.

Sakai S-I, Yoshida H, Hiratsuka J, et al. (2014) An international comparative study of end-of-life vehicle (ELV) recycling systems. *Journal of Material Cycles Waste Management* 16: 1–20.

Schmid A, Batton-Hubert M, Naquin P, et al. (2016) Multi-criteria evaluation of end-of-life vehicles' dismantling scenarios with respect to technical performance and sustainability issues. *Resources* 5: 42.

Simic V (2016a) A multi-stage interval-stochastic programming model for planning end-of-life vehicles allocation. *Journal of Cleaner Production* 115: 366–381.

Simic V (2016b) End-of-life vehicles allocation management under multiple uncertainties: an interval-parameter two-stage stochastic full-infinite programming approach. *Resources, Conservation and Recycling* 114: 1–17.

Simic V and Dimitrijevic B (2015) Interval linear programming model for long-term planning of vehicle recycling in the Republic of Serbia under uncertainty. *Waste Management & Research* 33: 114–129.

Stagner JA, Sagan B and Tam EKL (2013) Using sieving and pretreatment to separate plastics during end-of-life vehicle recycling. *Waste Management & Research* 31: 920–924.

Talib F, Rahman Z and Qureshi MN (2011) Prioritising the practices of total quality management: an analytic hierarchy process analysis for the service industries. *Total Quality Management & Business Excellence* 22: 1331–1351.

Tian G, Zhang H, Feng Y, et al. (2017) Operation patterns analysis of automotive components remanufacturing industry development in China. *Journal of Cleaner Production* 164: 1363–1375.

Tian J and Chen M (2016) Assessing the economics of processing end-of-life vehicles through manual dismantling. *Waste Management* 56: 384–395.

Tot B, Srđević B, Vujić B, et al. (2016) Evaluation of key driver categories influencing sustainable waste management development with the analytic hierarchy process (AHP): Serbia example. *Waste Management & Research* 34: 740–747.

Vinodh S and Jayakrishna K (2013) Application of hybrid MCDM approach for selecting the best tyre recycling process. In: Davim JP (ed) *Green Manufacturing Processes and Systems*. Berlin: Springer, pp.103–123.

Wang J and Chen M (2012) Management status of end-of-life vehicles and development strategies of used automotive electronic control components recycling industry in China. *Waste Management & Research* 30: 1198–1207.

Wilts H, Bringezu S, Bleischwitz R, et al. (2011) Challenges of metal recycling and an international covenant as possible instrument of a globally extended producer responsibility. *Waste Management & Research* 29: 902–910.

Xia X, Kannan G and Zhu Q (2015) Analyzing internal barriers for automotive parts remanufacturers in China using grey-DEMATEL approach. *Journal of Cleaner Production* 87: 811–825.

Zailani S, Govindan K, Shaharudin MR, et al. (2017) Barriers to product return management in automotive manufacturing firms in Malaysia. *Journal of Cleaner Production* 141: 22–40.

Zhang C and Chen M (2018) Prioritising alternatives for sustainable end-of-life vehicle disassembly in China using AHP methodology. *Technology Analysis and Strategic Management* 30: 556–568.

Zhou F, Lin Y, Wang X, et al. (2016) ELV recycling service provider selection using the hybrid MCDM method: a case application in China. *Sustainability* 8: 482.

Ziout A, Azab A and Atwan M (2014) A holistic approach for decision on selection of end-of-life products recovery options. *Journal of Cleaner Production* 65: 497–516.