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An Improved Framework for Managing Uncertainties in Vehicle Recycling: A Case Study Approach at Multiple Malaysian Automotive Treatment Facilities (ATF)

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Abstract

The legislation for end-of-life vehicles (ELV) is anticipated to be fully enforced, and public awareness is likely to grow over the next few years, assuring the profitability of Malaysia's ELV recycling enterprises in the future. However, the current state of ELV recycling operations is fraught with uncertainty, which has hampered this industry's expansion. Thus, this study aims to identify critical uncertainties and provide suitable strategies to mitigate these uncertainties. A case study of multiple automotive treatment facilities (ATFs) in Malaysia was employed to conduct this study. A structured questionnaire comprising both closed-ended and open-ended questions was provided to Malaysian ATFs, and site observations were conducted to investigate the ATFs' production settings. Cross-case synthesis was utilised to compare the cases studied. Meanwhile, the closed-ended questions are assessed on a five-point Likert scale, and the responses were analysed with ATF to conduct the descriptive analysis. As a result, a cross-case synthesis between the ATFs was presented and the uncertainties in ELV recycling operation were identified, consisting of ELV supply (M = 4.250), ELV recycling costs (M = 4.188), ATF infrastructure (M = 4.125), production planning (M = 3.875), ELV characteristics (M = 3.550), and ELV distribution network (M = 2.833). In addition, a conceptual framework for improving the ELV dismantling system in Malaysia's ATF was proposed. The novelty of this study is a detailed analysis of existing uncertainties in ELV recycling operation in the Malaysian context and an improved framework to enhance the ELV dismantling system for ATFs in Malaysia.

1. Introduction

The enormous demand for automobiles in Malaysia predicts that even more automotive waste will be generated in the coming years [1]. According to the Malaysian Automotive Association [2], the number of registered vehicles in Malaysia during the previous ten years was 6,711,065, with passenger cars accounting for 91.88 % and commercial vehicles accounting for the remaining 8.12 %. Furthermore, the overall production volume in Malaysia's automobile sector is expected to expand over the next five years [2] progressively. Eventually, as the vehicles no longer can be utilised, it will be a type of waste called the end-of-life vehicle (ELV) [3]. The ELV consists of numerous types of waste, including metals, rubber, glass and others [4]. Nonetheless, Malaysia only recycled 28.1 % of its waste in 2018, including plastics, paper, aluminium, metals, glass, and various forms of waste [5]. This data shows that Malaysia generates a significant pile of waste; yet, efforts to minimise waste are still limited, particularly in the ELV sector, where most ELVs are discarded in landfills or incinerated [6].

Clouded by the fact that the ELV recycling business is highly uncertain, various supply chain uncertainties are predicted to exist in the ELV ecosystem, creating a quandary for entrepreneurs when making decisions. Supply chain uncertainty refers to a situation in which decision-makers are hesitant to propose decisions due to an unclear objective; insufficient knowledge about the supply chain and its environment; insufficient ability to process data; inability to anticipate the impact of management strategies on the supply chain; or inefficient management mechanism [7]. These supply chain uncertainties can subside by using an appropriate uncertainty management approach. Thus, it is necessary to identify the cause of supply chain uncertainty to manage it effectively. This article discusses a few supply chain uncertainty sources to explain supply chain uncertainty in the ELV recycling ecosystem. The supply chain uncertainty sources include the ELV characteristics, production planning at automotive treatment facilities (ATF), facility, and infrastructure in the ATF, ELV supply, ELV recycling cost and the ELV distribution network.

Despite that, a few ELV studies described in the literature tend to focus on ELV recovery in Malaysia, such as Mohamad-Ali et al. [8], Raja Mamat et al. [9], Go et al. [10], Jawi et al. [11] and Harun et al. [12]. Meanwhile, Amelia et al. [13] and Mat Ropi et al. [14] examined the ELV reuse implementation and the automotive remanufacturing operation in Malaysia, respectively, in previous studies. A comprehensive investigation of ELV recycling operations in Malaysia has not yet been conducted; hence, this study seeks to fill this gap in the literature by presenting a case study analysis of ATF in Malaysia, which can provide an overview of the uncertainties in the ELV recycling industry. In addition, there are a few related studies in the literature concentrating on the ELV industry's challenges [13], influencing factors [8], [9], disruption risk in supply chain management [14], and policy [10]–[12]. Considering this, it is reasonable to conclude that the majority of previous ELV studies conducted in the Malaysian context focused on barriers, success factors, and regulations. Nonetheless, a detailed examination of the operational uncertainties in Malaysia’s ELV supply chain has not yet been conducted.

Guided by these points, it is critical to analyse and emphasise the uncertainties that lie in the ELV recycling system and recommend possible solutions to alleviate the uncertainties. Using a case study of several ATFs in Malaysia, this study sought to uncover the existing uncertainties in ELV recycling operations. Moreover, this study proposes a framework to improve the ELV dismantling system for mitigating ambiguity in ELV recycling facilities. The contribution of this study is an overview of the uncertainties affecting the ELV recycling industry in Malaysia and a conceptual framework for enhancing the ELV dismantling system in the ATF.

The structure of this paper is as follows: Section 2 describes the methodology adopted in this study and the case study company’s background. Meanwhile, Section 3 explains and discusses the results of this study. Lastly, Section 4 concludes this research work.

2. Methodology

2.1 Research Design

This research adopted an exploratory case study technique [15], guided by the research topics and current literature while emphasizing the ELV recycling operation. Hence, this study reveals the uncertainties that affect the ELV recycling industry in Malaysia using a case study comprising multiple locations [15]. The data collection approach includes a semi-structured interview, site observation and documentation. Owing to that, 4 companies were analysed in this study to examine the supply chain uncertainties that exist in the Malaysia’s ELV recycling industry. According to the Department of Environment (DOE) [16], only two ATFs are authorized to treat ELV in Malaysia, since the ELV recycling industry in Malaysia is still in its infancy. Thus, the number of participants in this study is relatively limited, and the organisations chosen to participate in this study are hand-picked, with only those companies actively involved in ELV recycling invited to engage in this study. Furthermore, the employees in selected organisations have an average of 20 employees per company, and the supply chain specialists are less than 5 personnel per organisation. Hence, the respondents for the case study were limited to one person for each company. In this case, snowball sampling was used to choose the respondent for this study [17].

2.2 Case Study Methods

The semi-structured interview approach was adopted as the methodology in this case study, specifically, using the structured questionnaire. The structured questionnaire consists of several closed-ended questions and is supported by open-ended questions to obtain comprehensive findings from the semi-structured interview. The structured questionnaire was divided into seven sections and the summary of the structured questionnaire is presented in Table 1. The questions in the structured questionnaire were generated from previous studies that explored the ambiguity in ELV recovery operations [14], [18], [19].

Table 1 *The summarised content of the structured questionnaire*

Section	Description	Explanation
1	General information of participants	Company background, general information regarding ELV recycling operation and respondents' working experience.
2	Issues in obtaining ELV supply	Factors that might affect the ELV supply include the illegal spare part business, transportation issues, low technology adaptation and the long duration of obtaining ELV supply.
3	Influence of ELV technical data on recycling operation	The physical condition of ELV and ELV utilisation level.
4	Production capacity issues in the ELV recycling operation	Production planning issues such as production line, idle time, and operating time.
5	ELV distribution network	ELV network distribution issues, for instance, the cost, effectiveness of delivery and duration of delivery.
6	Costs in ELV recycling operation	The ambiguity in ELV recycling costs includes the production cost, depollution cost and overhead cost.
7	Infrastructure and facilities in ELV recycling operation	Issues related to the machinery and equipment in the ATF, automation level, manpower and warehouse.

The closed-ended questions are a series of questions using the five-point Likert scale to ascertain the degree of ambiguity on each topic, and the Likert scale varied from 1 to 5, which are 1= Strongly disagree, 2= Disagree, 3= Neutral, 4= Agree and 5= Strongly Agree. The closed-ended questions were designed with the Likert scale to facilitate the analysis of the findings for the case study. The open-ended questions, on the other hand, are made up of many inquiries that complement the closed-ended questions to elicit thorough responses from the respondents. In the first instance, a supply chain expert in supply chain management and ELV management was asked to validate the questionnaire. After that, a pilot test was also conducted at a waste management organisation with expertise in ELV management and treatment, making them suitable candidates to verify the questions. The company was asked to answer the questionnaire and identify any problems in meaning and terminology. This approach-maintained reliability during the subsequent case study analysis being performed.

At the same time, site observations and documentation also were performed among the ATFs to explore the uncertainties in different production settings. This study incorporates the site observation and documentation approach since it is an effective technique for explaining and correlating the semi-structured interview findings [15]. Additionally, the process flow of the ELV recycling process was observed during the site observation, as well as the facilities, machinery, and technological adaption in the ATF.

Table 2 *Description of respondents in the semi-structured interview*

Company	Business Background	Respondent	Working Experience	Approach
A	ELV Dismantling	Managing Director	>10 years	Email interview and a face-to-face interview
B	Waste Management	Executive	5-10 years	Email interviews and phone calls
C	Scrap and Recycling Specialist	Manager	>10 years	Video conferencing interviews and email interviews
D	Remediation Activities and Other Waste Management Services	Chief Executive Officer	>10 years	Email interviews and phone calls

2.3 Data Collection

During the data collection phase, emails were sent to each of the firms on the list inviting them to participate in this study, and some of them were also reached by phone. Four replies were received in response to ten emails sent which makes the response rate 40%. The ATFs involved in this study were labelled anonymously using the alphabets, Company A, B, C, and D. The list of respondents is listed in Table 2. Next, the questionnaires were sent to the company's executive personnel via email. The purpose of the research was clearly described to them, and each respondent's name and work description were registered before sending the questionnaire. Respondents were given a week to complete the questionnaire. The data was collected using a variety of approaches, including email interviews, video conferencing interviews, phone calls, and face-to-face interviews.

2.4 Data Analysis Techniques

Descriptive analysis was employed to examine the responses for the closed-ended questions by using Statistical Package for the Social Sciences (SPSS) software, in which the mean (M) and standard deviation (SD) from the responses collected were computed. This study is being conducted in a niche industry with a limited number of stakeholders; thus, the number of participants in this study is small; however, the standard deviation should be calculated to obtain a measure of the dispersion of supply chain uncertainty sources in Malaysia's ELV recycling industry. The value of the mean was examined in this study to obtain a single value that summarises a dataset and illustrates the average value of the supply chain uncertainty source [20]. On the other hand, the value of standard deviation was analysed to acquire the degree of dispersion of responses from the participants [20]. These two measurements are crucial in this study to determine the main supply chain uncertainty sources and the uncertain variables in Malaysia's ELV recycling industry.

Apart from that, the cross-case synthesis approach was utilised to interpret and integrate the findings from the structured questionnaire [15]. The open-ended and closed-ended responses were compiled and reorganised; comparisons were performed between the classed data to gain in-depth knowledge of each case. On the other hand, from the site observation conducted, a company was chosen to replicate their ELV recycling process flow. Based on the selected case, an enhanced process flow was then recommended to improve the production flow in the ATF.

3. Case Study Results and Discussion

3.1 Cross-case Synthesis Findings

The description of the cases involved in this study was analysed using the cross-case synthesis technique as has been discussed in the previous section, and the findings are tabulated in Table 3. The companies' current state and fundamental background were described under numerous uncertain aspects, including ELV supply, ELV recycling costs, facilities and infrastructure, production, ELV characteristics, and ELV distribution network. The importance of these uncertainties has been emphasised by past researchers [7], [19], [21]. The case study findings are further discussed in the following sections based on the collected data.

Table 3 *Brief description of investigated ATF*

Company / Uncertainty	Company A	Company B	Company C	Company D
Introduction	This company is an authorised ATF in Malaysia, which had been granted an official license from the DOE to administer ELV treatment. This ATF can handle up to 850 automobiles each month. This business is based in Malaysia's central area and has been operating since October 2018. This business dismantled the ELV using a semi-automated procedure. This company is the major industrial player in the ELV recycling industry in Malaysia. This	This organisation provides environmental solutions to various organisations, including ELV treatment services. In 2014, this organisation began participating in the processing of ELV and is now obtaining an official license from DOE to execute ELV treatment activities. Their ELV facility is in Malaysia's central area and is intended to handle up to 200 automobiles each	This company has been recycling metal scrap for over 30 years and is now recycling other types of waste, including non-metal waste and ELV. This company employ manual methods to dismantle ELVs and can process less than 50 vehicles per month. This company is in Malaysia's	This organisation had been granted formal approval from DOE to perform ELV treatment activities. This company is in central Malaysia and is expected to recycle around 600 automobiles every month. They began operations at the end of 2019. Their recycling facility is equipped with semi-automated machinery for ELV processing, and they are working toward

	company also intends to upgrade the ATF by adopting advanced ELV recycling technology.	month.	central area and offers an ecologically safe solution for ELV that complies with Malaysian regulations.	establishing an integrated ELV facility.
ELV Supply	They are experiencing significant difficulties with the ELV flow and supplier lead time. Additionally, unlawful spare part sales and a lack of technological adaptability significantly affect the recycling process.	ELV flow is the main supply uncertainty in this company. Besides that, ELV recycling is also disrupted by supply lead times, limited technology adoption, and transportation.	This company's key challenges regarding the ELV supply are inconsistent ELV flow, lengthy supply lead time, and limited technological adaptability. The illicit spare component trade also impacts the supply of ELVs.	This company experienced unstable ELV supply owing to unpredictable ELV flows, lengthy supply lead times, illegal spare part business, limited technological adaption, and transportation constraints.
ELV Recycling Cost	They emphasise that these elements add up to a significant cost for recycling: dismantling and flattening ELV; separating materials; transporting the ELV; paying workers; utility prices; maintenance; depollution; and treating dangerous chemicals.	They stated that dismantling and flattening, material separation, transportation, inventories, labour expenses, utility costs, depollution, and the treatment of hazardous chemicals all contribute to the high cost of ELV recycling.	They specified that recycling ELVs is very costly because it entails disassembling and flattening ELVs, separating materials, paying workers' salaries and other overhead, purchasing, and maintaining inventories, performing other routine maintenance, treating hazardous chemicals and depollution.	They invested a substantial sum of money in material separation, depollution, and treatment of dangerous chemicals. Furthermore, dismantling and flattening ELVs costs a lot, but so does ELV shipping and facility maintenance.
Facilities and Infrastructure	They stated that the ELV recycling process is severely hampered by infrastructural concerns such as a lack of equipment, low automation levels, and a shortage of professionals. Similarly, the ELV recycling process is hindered by excessive	They have infrastructure concerns, such as inadequate equipment, poor automation level, and lack of ELV storage capacity, impacting the ELV recycling process.	They experience infrastructure difficulties, including inadequate equipment, a low degree of automation, and a shortage of professionals, which directly	The ELV recycling activity in this company is seriously affected by infrastructure problems, including insufficient equipment, a low degree of automation, and a shortage of ELV

	downtime.		impact the ELV recycling process.	storage capacity.
Production	ELV recycling in this company is greatly influenced by prolonged idle time. The operation is somewhat affected by issues with the serial production line and inventories caused by uncertain ELV supply.	This company stated that long dismantle processing times lead to inventory difficulties. Moreover, the serial production line and inventory concerns caused by uncertain ELV supplies also cause production instability.	They emphasise that serial production lines and lengthy idle times cause inefficient production systems. In addition, inventory concerns caused by inconsistent ELV supply and extensive dismantle processing time also affect the ELV recycling process.	This company encounters several production issues, such as inventory issues, inefficiency due to serial production lines, and excessive downtime, leading to production setbacks.
ELV Characteristics	Their recycling procedure is greatly influenced by the type, maintenance level, and utilisation level of the ELV.	In this company, the age of the vehicle, mileage, ELV type, and ELV maintenance level all significantly impact recycling.	This company justified that the recycling process is considerably influenced by the vehicle's age, total miles, ELV type, ELV maintenance level, and ELV utilisation level.	They emphasise that vehicles' age and type of ELV have a huge impact on the recycling process. Additionally, the maintenance level has an important effect on the recycling process.
ELV Distribution Network	They clarify that the ELV distribution network is inefficient, expensive, and time-consuming.	The ELV delivery network for this company is extremely efficient and reasonably priced, and the shipping was expedited.	The ELV distribution network for this company is very efficient, cost-effective, and expeditious.	They are experiencing several problems with the ELV distribution network: it is inefficient, very costly, and time-consuming.

3.2 Overview of Supply Chain Uncertainty in ELV Recycling

The case study findings were explained using the mean and standard deviation. Fig. 1 summarises this case study by displaying the mean and standard deviation of supply chain uncertainty in an ELV recycling operation. As illustrated in Fig. 1, the ELV supply uncertainty (M = 4.250, SD = 0.526) indicates that the participating companies believe ELV supply is a significant issue in the ELV recycling market. This discovery is consistent with the prior studies [19], [21], indicating that ELV supply substantially influences ELV recycling operations.

Furthermore, the ELV recycling cost (M = 4.188) and ATF infrastructure (M = 4.125) resulted in a high mean value, indicating that these uncertainties are significant concerns in the ELV recycling sector. The low standard deviation for ELV recycling costs (SD = 0.472) and ATF infrastructure (SD = 0.433) demonstrates that respondents have similar views on these subjects. The findings on the ELV recycling cost uncertainty are consistent with Simic [19]. Meanwhile, the outcome of ATF infrastructure uncertainty is in line with past studies as such was conducted by Zhang & Chen [22].

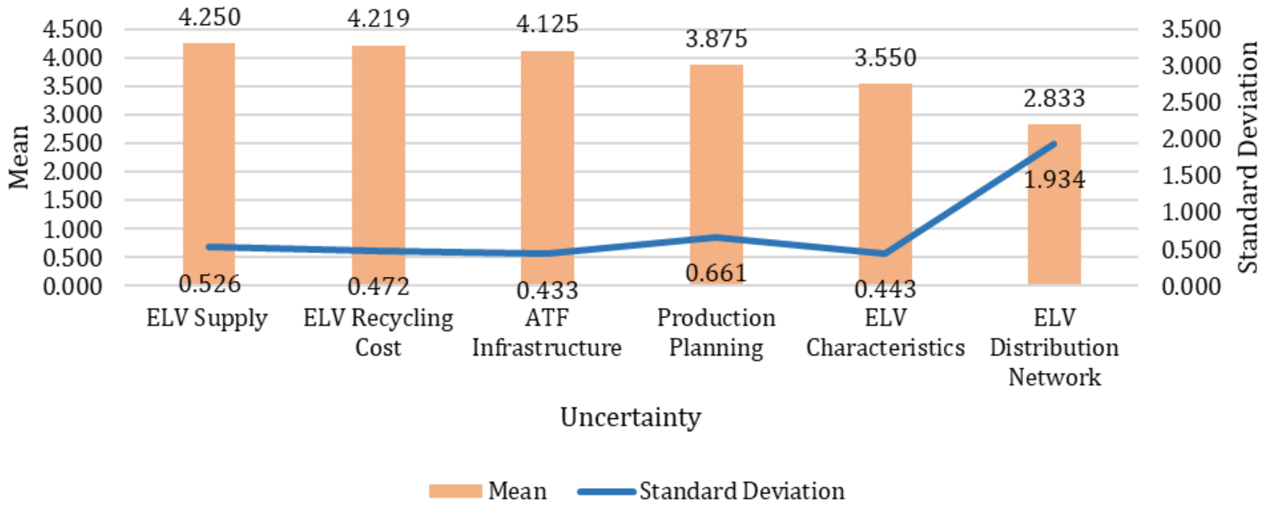

Fig. 1 *Overview of supply chain uncertainty in ELV recycling*

Moreover, the intermediate mean values for production planning (M = 3.875) and ELV characteristics (M = 3.550) indicate that these variables moderately affect the ELV recycling operations. The low standard deviations range for production planning (SD = 0.661), and ELV characteristics (SD = 0.443) show that all respondents agreed that these uncertainties moderately influence the ELV recycling activity.

On the other hand, the ELV distribution network has the lowest mean (M= 2.833), showing that this uncertainty has little effect on the ELV recycling sector. Nonetheless, the large standard deviation (SD = 1.934) indicates that respondents are divided on this subject, with half agreeing that the ELV distribution network is efficient and the other half disagreeing. The findings are explainable after reviewing the company's background, where two of the companies have established their distribution network to obtain the ELV supply, while the other two companies are currently expanding their distribution network. The following sub-section describes in depth the uncertainties associated with the ELV recycling industry in Malaysia, including ELV supply, ELV recycling cost, ATF infrastructure, production planning, ELV characteristics, and ELV distribution network.

3.2.1 Uncertainty in ELV Supply

The fluctuating supply of ELV has a huge impact on the functioning of the ELV recycling facility. According to Fig. 2, there are three primary causes of irregularity in ELV supply. Several factors contribute to this, including an uncertain ELV flow (M = 5.00), a lengthy supply lead time (M = 4.75), and a lack of technological adoption (M = 4.50). Additionally, all respondents agreed that an uncertain ELV flow results in ambiguity in ELV supply. The low standard deviation shows that all respondents have the same view. Numerous previous research, such as Mohan & Amit [21] and Govindan & Gholizadeh [23], substantiate this conclusion.

Similarly, a high mean value and a small standard deviation range are seen for the statements: lengthy supplier lead time (M = 4.75, SD = 0.50) and lack of technological adoption (M = 4.50, SD = 0.577), indicating that these two constraints significantly influence the ELV recycling process. Most respondents agreed with this claim. Similarly, Hao et al. [24] addressed the lengthy supplier lead time in their investigations, and the poor level of technological adaptation in ELV recycling operations has been significantly mentioned in studies performed by Ahmed et al. [25] and Raja Mamat et al.[26].

3.2.2 Uncertainty on ELV Recycling Expenses

In every business, production expenses are critical. Every practitioner strives for the lowest possible cost for their production system. Nonetheless, as shown in Fig. 3, several aspects of ELV recycling consume high costs, such as the cost of separating metal and non-metal waste (M = 4.75), dismantling and flattening costs (M = 4.50), expenses for depollution and hazardous substance treatment (M = 4.50), operators wages (M = 4.25), utility (M = 4.25), and maintenance costs (M = 4.00). These results are congruent with the debate in the previous study [27], [28]. Moreover, the standard deviation range for metal and non-metal waste separation costs (SD = 0.50), dismantling and flattening costs (SD = 0.577), and costs for depollution and hazardous material treatment (SD = 0.577) is small, implying that most respondents believed that these costs are quite expensive.

In contrast, a wider standard deviation range is noted for operator wages (SD = 0.957), utility costs (SD = 0.957), maintenance costs (SD = 0.816), and transportation costs (SD = 1.258), revealing that these expenses vary depending on the company's facilities. Different situations can be observed for inventory cost (M = 3.750, SD = 0.500), which shows a low standard deviation range and high mean value, indicating that all respondents claimed that inventory does not need substantial amounts of money.

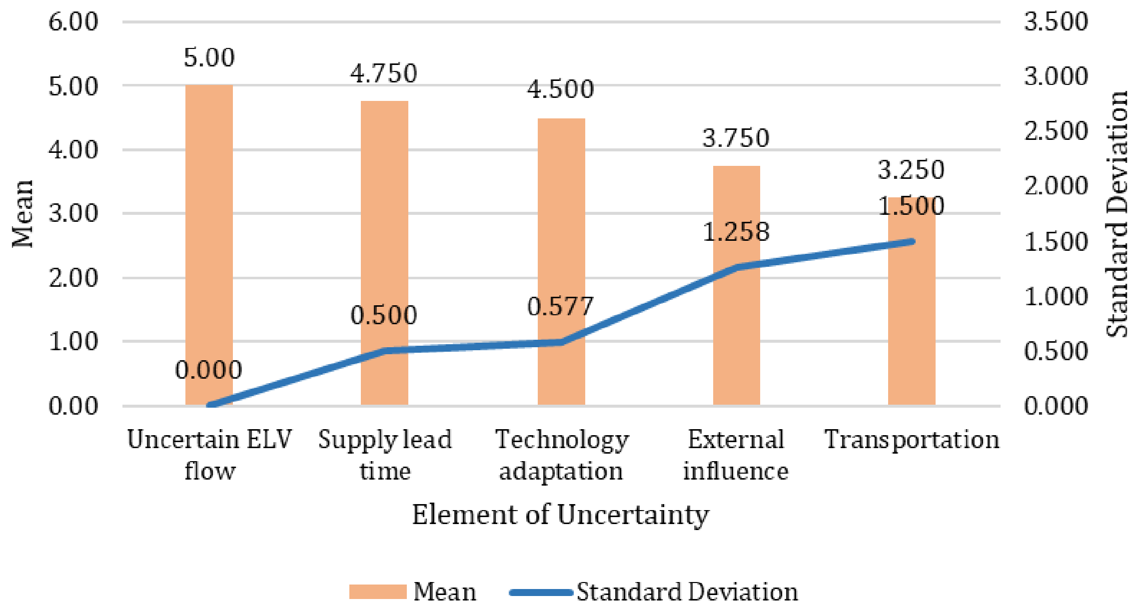

Fig. 2 *ELV supply uncertainty*

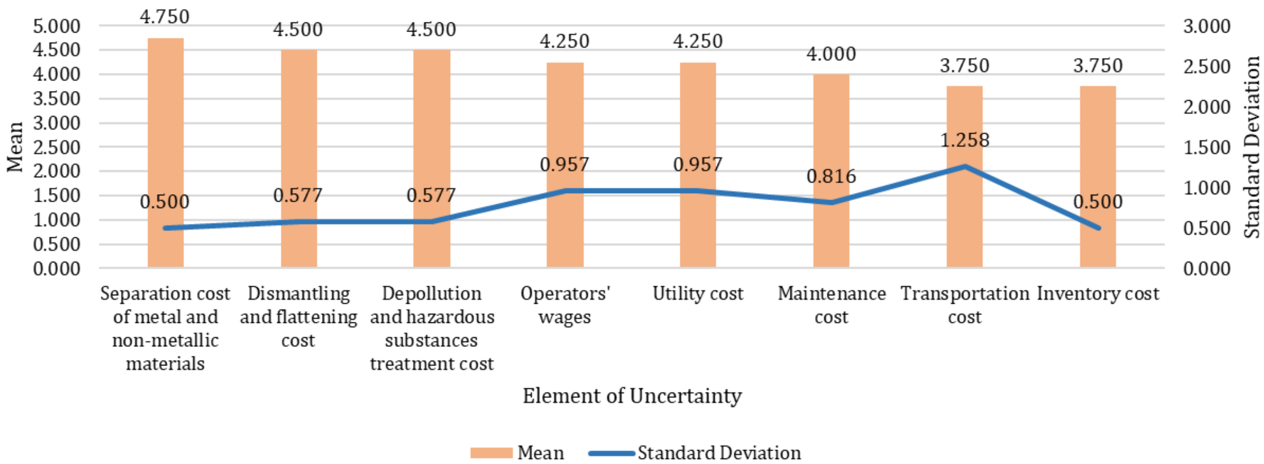

Fig. 3 *ELV recycling cost*

3.2.3 Facility and Infrastructure Uncertainty

ATFs must have adequate infrastructure and facilities to facilitate the recycling of ELVs. Inadequate equipment and a lack of technological adaption will result in an ineffective ELV recycling process. According to Fig. 4, inadequate equipment (M = 4.50) and a low degree of automation (M = 4.50) significantly influenced the ATF infrastructure, resulting in inefficient ELV recycling. These findings corroborate the prior study's contentions conducted by Ahmed et al. [25], Go et al. [10], and Zhang & Chen [29]. The low standard deviation indicates that most respondents confront a similar issue at work.

On the other hand, a greater standard deviation range for the workforce (SD = 0.957) and storage issues (SD = 0.957) indicates that not all participating companies encounter the same workforce and storing area difficulty, which explains the lower mean value for both criteria. This finding shows that most respondents have substantial concerns with limited equipment and poor automation in the dismantling process for ELV recycling; however, not all respondents experience challenges with workforce and storage.

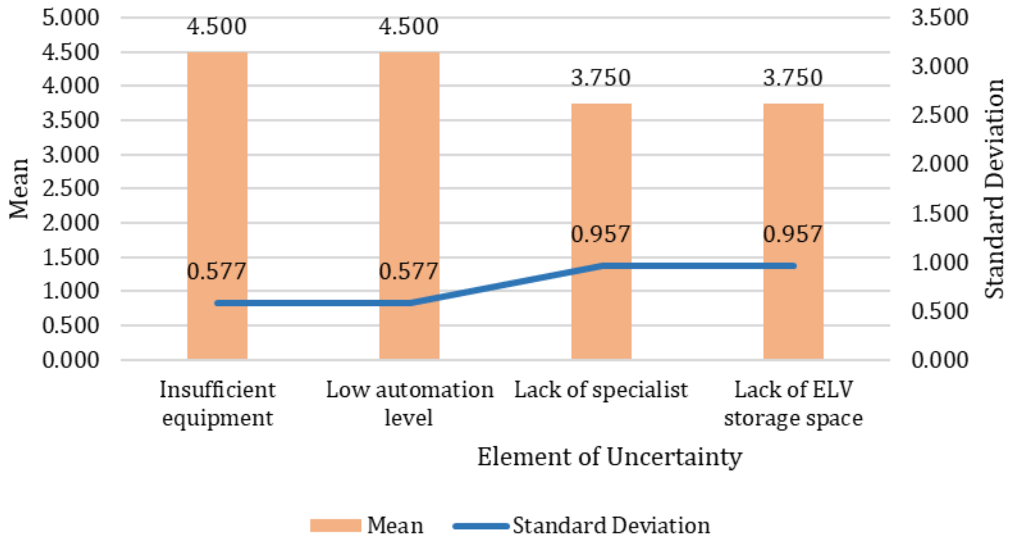

Fig. 4 *Facilities and infrastructure uncertainty*

3.2.4 Uncertainty in Production Planning

Scheduled and organised production assures the timely delivery of produced items. Production plans are essential to ensure the resources are used efficiently and keep operations operating smoothly. The case study's results (Fig. 5) indicate that various production concerns contribute to production uncertainty. The mean value for serial production line (M = 4.25), long idle time (M = 4.00), and inventory issues due to uncertain ELV supply (M = 4.00) are all high, suggesting that most respondents experienced these concerns contributing to production uncertainty. This result corroborates past research on the production challenges [22], [30].

The standard deviation range is not large, indicating that most case study participants encounter similar production challenges in their ELV facility related to the serial production line (SD = 0.957) and inventory issues (SD = 0.816). However, since the standard deviation is not so small, it is possible to deduce that certain respondents have fewer production system concerns. Nonetheless, the substantial variance reported for long idle time (SD = 1.414) and long dismantling processing time (SD = 1.500) implies respondent inconsistency. This finding indicates that certain ATFs have difficulties with long idle time and dismantling periods, while some do not have these issues.

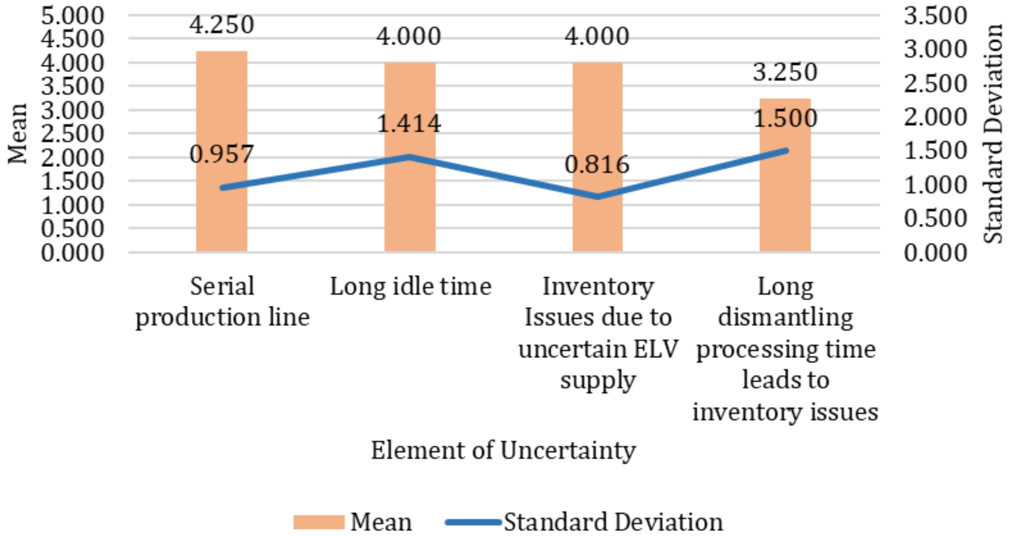

Fig. 5 *Production planning uncertainty*

3.2.5 Uncertain ELV Features

The condition of ELV, which includes the vehicle's characteristics and features, is inconsistent and influences the ELV recycling operation [19]. As shown in Fig. 6, several criteria are observed related to ELV characteristics. Firstly, the finding demonstrates that the type of ELV (M = 4.00) has a significant impact on ELV recycling operation. This finding is consistent with [19], which discovered that the ELV variant affects recycling activity.

Other than that, the vehicle age (M = 3.75), maintenance level (M = 3.75), utilisation level (M = 3.25), and total mileage (M = 3.00) moderately affect ELV recycling operation. This response is related to Malaysia's current situation in which abandoned cars are the vehicle that is commonly being treated for ELV by the ATF [31]. Therefore, there is less variability in vehicle age, maintenance level, utilisation level, and total mileage among the treated ELVs since abandoned vehicles in Malaysia are mostly old and overutilized vehicles.

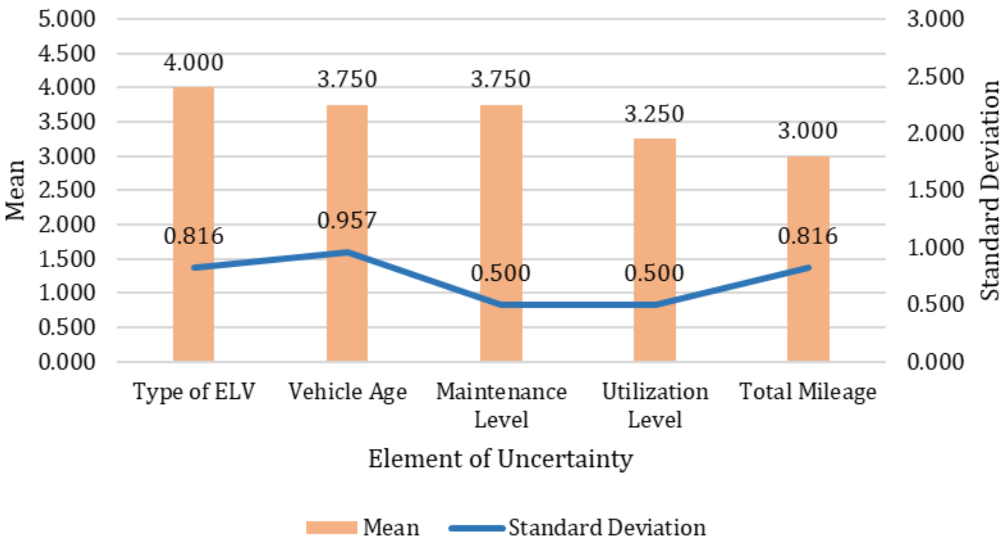

Fig. 6 *Uncertain ELV features*

The low standard deviation range concluded that all respondents were on the same page that maintenance level (SD = 0.50) and utilisation level (SD = 0.50) moderately affect the ELV recycling operation due to the maintenance level and utilisation level of the ELV being treated in their facility is about the same. Whereas a slightly higher range of standard deviation on the ELV type (SD = 0. 816), vehicle age (SD = 0.957) and total mileage (SD = 0.816) indicates that these criteria are fairly inconsistent. Certain companies are confident that these criteria significantly impact the ELV recycling characteristics, while some believe these criteria moderately influence the ELV recycling activity. This contradictory reaction is because the participating companies acquire their ELV supply from various sources, resulting in various ELV attributes. Different production setting in their facilities also influences their responses to this issue.

3.2.6 ELV Distribution Network Uncertainty

The ELV distribution network is the connection that links uncollected ELV to the ELV treatment facility. Well-organised network distribution is crucial since it ensures a seamless ELV recycling operation [30]. For this reason, the queries in this case study also contain ELV distribution network enquiries. As a result, the findings in Fig. 7 show a low mean value for the distribution network cost (M = 3.00), efficiency (M = 2.750) and short duration to supply ELV (M = 2.750), demonstrating there is a contradiction in the responses. A large variation in the standard deviation could be observed, indicating that the respondents were not on the same page with this issue.

These data indicate that certain companies have difficulty managing the ELV distribution network, whilst others do not have difficulty controlling the distribution network. This situation is understandable because the participating companies do not share the same ELV distribution network. Some companies have a good distribution network, while others are still developing and adjusting their distribution network to work efficiently and supply ELV on time with minimal cost, as always emphasised in previous studies, for example, Govindan & Gholizadeh [23].

3.3 Managing Uncertainty of ELV Recycling in ATFs

The uncertainties regarding Malaysian ATF were thoroughly investigated and analysed in previous sections. According to the analysis, three prominent uncertainties jeopardise Malaysia's ELV recycling operation: ELV supply, ELV recycling cost, and ATF infrastructure. Thus, this research is expanded by examining one of the collaborating companies to construct a model capable of proposing a solution and mitigating supply chain uncertainty in ELV recycling operations. For this reason, Company A was investigated in further detail, and extended observations were conducted for a deeper comprehension of the ELV recycling process performed in their facility. As a result, this company's ELV recycling process flow is depicted in Fig. 8.

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The ELV recycling process is initiated with the vehicle deregistration procedure. The ELV is then delivered to the ATF upon completion of the process. As illustrated in Fig. 8, ELV is obtained in three ways: directly from end-users, via local authorities, and through insurance companies. The process begins with an inspection at the weighing station, in which the weight of the ELV is calculated, and other pertinent information is recorded. A QR code containing vehicle data is produced, and the ELV is labelled with the QR code to ensure total traceability.

The procedure is then followed with depollution and hazardous material removal, which includes the removal of petrol fuel, engine oil, gearbox oil, brake oil, power steering oil, windshield washer fluid, and refrigerants (chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs)). Simultaneously, the ELV's airbag is neutralised at the airbag deployment station. The depollution procedure is completed by collecting all hazardous materials by scheduled waste contractors to allow safe chemical disposal.

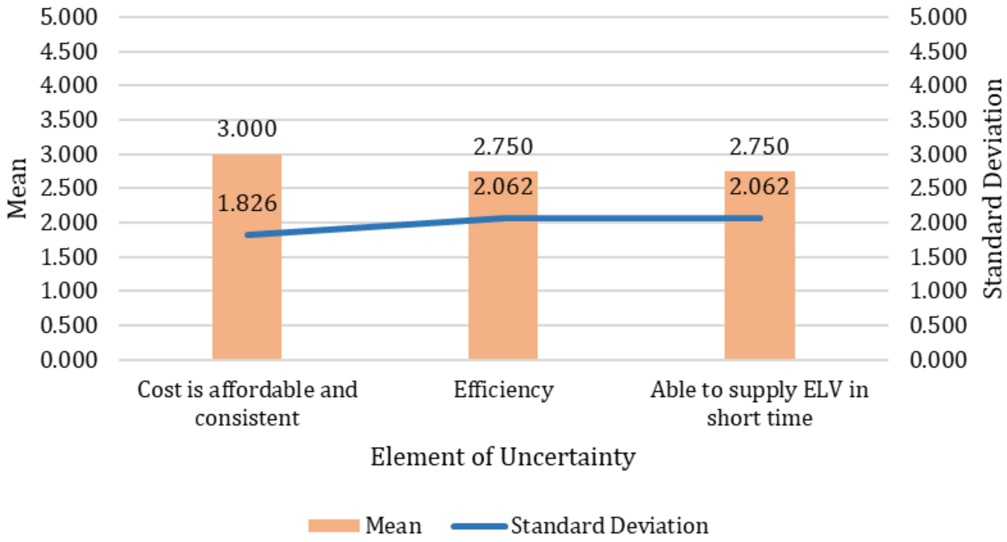

Fig. 7 *ELV distribution network uncertainty*

Next, manual dismantling is performed at the manual disassembly station. This station dismantles lightweight and mediumweight components. The headlamps, engine control unit (ECU), radio, and steering are lightweight components dismantled at this station. The reusable components are retained for future use, while the damaged components are recycled. Mediumweight components such as doors, bonnets, panels, and seats are dismantled in this station if they are in excellent shape and can be reused; otherwise, they are dismantled at the next station to shorten the dismantling process. Additionally, a tyre separation machine is employed at this station to detach tyres from their wheel rims effectively.

The following station is a semi-automatic dismantling station where a separation machine is used to separate heavyweight components and vehicle components that are too dangerous to be handled manually, such as automobile engines and transmission systems. This station separates ferrous, non-ferrous, and non-metal components before transporting them to recyclers. Finally, all recoverable components are sold to automotive components suppliers, while recyclable materials are recycled, and obsolete parts are dumped in landfills.

The ELV recycling process was reviewed in conjunction with the uncertainties discovered during the preliminary part of this research. Based on the observation, it can be concluded that this ATF faces many issues, for instance, uncertain ELV supply, low productivity at the dismantling station, high operational costs, and low technology adaptation. Therefore, a solution is needed that incorporates a strategy for reducing the supply chain uncertainties identified specifically to ensure the ATF's long-term viability.

Given these points, Rickli & Camelio [32] described dismantling an end-of-life (EOL) product in partial dismantling, selective dismantling, and total dismantling. Partial dismantling is typically performed on highly uncertain EOL products, in which the potential recovered parts cannot be accurately predicted before the dismantling process, as some components may be removed before disposal or damaged during use, or the EOL product contains irreversible components [33]. Additionally, partial dismantling is often employed when disassembly costs exceed the profit generated by recoverable components [32], [33]. Meanwhile, selective disassembly is mostly adopted to secure valuable components while discarding others [22], [32]. In contrast, total dismantling refers to the complete breakdown of EOL products into their parts [22], [32].

At the same time, numerous factors need to be considered while enhancing the dismantling systems. Previous research has addressed the need to evaluate the ELV structure and material before dismantling to enhance productivity [22], [34]. Additionally, batching products for a dismantling line is problematic due to the variable operating lifespan of the ELV and dismantling patterns; thus, ELV must be categorised and stored to provide the dismantling line with identical ELV conditions simultaneously [22]. Moreover, excluding the depollution process from the dismantling operation is advisable to ensure better process flow [22], [35]. Hence, in the final analysis, a framework for improving the ELV recycling process flow in Company A was designed.

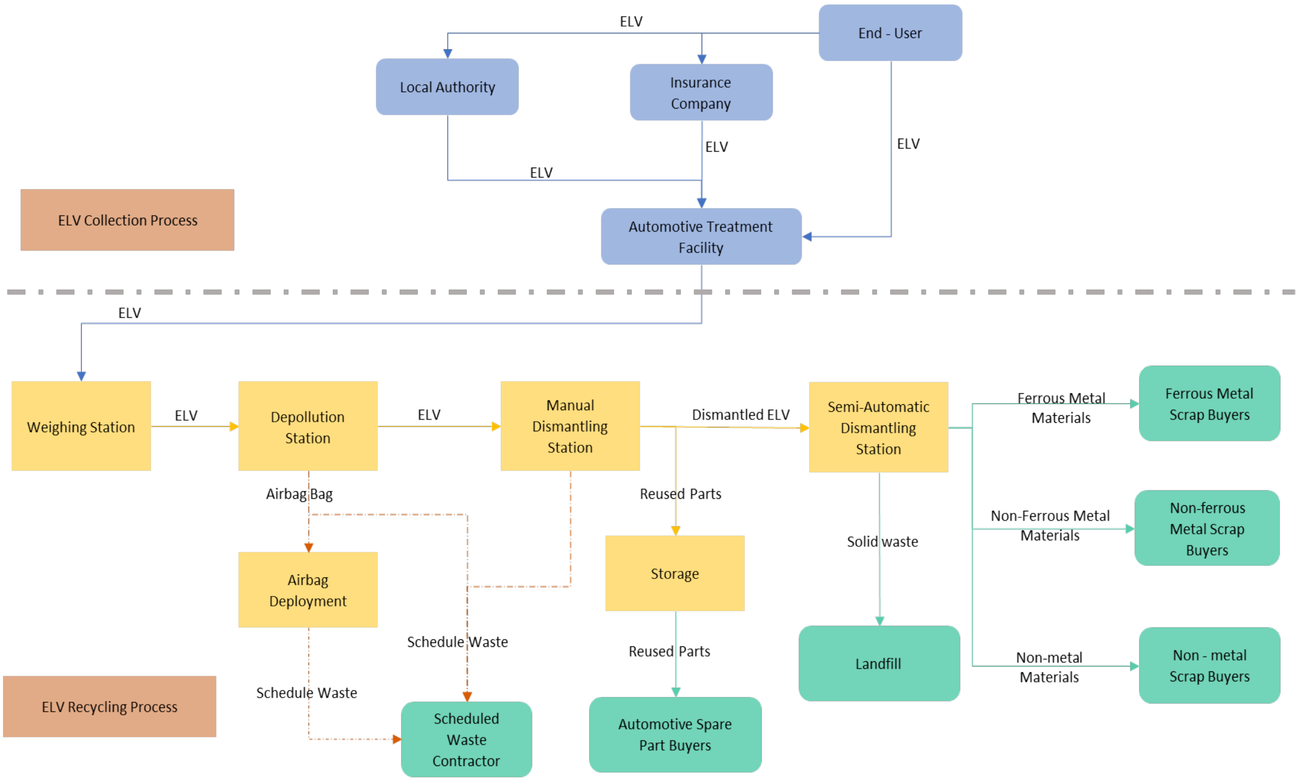

Fig. 8 *Simplified process flow for ELV recycling (Company A)*

3.3.1 A Conceptual Framework for ATF's ELV Recycling System

The conceptual framework shown in Fig. 9 illustrates a strategy to improve the ELV recycling process based on the recycling activity at Company A. This conceptual framework was verified by ELV experts using the Delphi method. The verification process comprises two rounds of verification. In the first round, opinions are collected through open-ended questions. These questions primarily address general feedback aimed at enhancing the framework and gathering insights on its implementation in the industry and its potential for improving production flow. The conceptual framework was improved based on the comments from the experts in the first round. Next, the subsequent iteration involves the validation of the revised framework by the administration of a questionnaire utilising a five-point Likert scale. The scale encompasses a range of responses, with (1) representing strong disagreement and (5) indicating strong agreement. The evaluation of the conceptual framework was conducted by assessing its structural design, which is particular to the comprehension of the conceptual framework (score: 4), the clarity of the design (score: 5) and the compatibility of the design (score: 5). In addition, the conceptual framework was assessed based on the feasibility of the framework. The feasibility of the conceptual framework was assessed by considering the adaptability (score: 4.5), the practicability (score: 4) and the realistic aspect (score: 4.5). Besides that, the conceptual framework also was evaluated based on its efficacy in lowering production time (score: 5) and enhancing production flow (score: 5). Therefore, the framework is confirmed since the experts have reached a consensus and each item has received a score of more than 3.7 and a third round of verification is not required [36].

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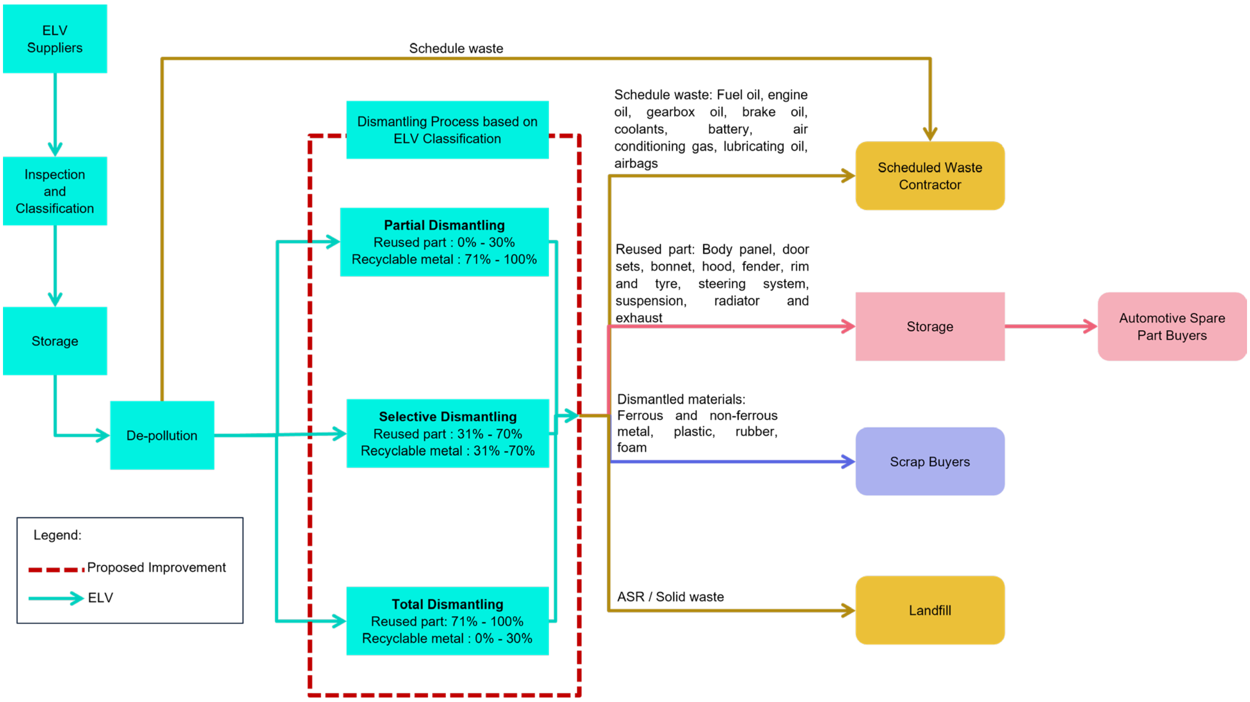

Fig. 9 *Conceptual framework to improve the ELV recycling operation*

The ELV recycling process begins with the collection of ELV from the provider, as can be observed in Fig. 9. Then, the inspection and the ELV classification procedure will be executed by skilled workers who at least qualify for a Malaysian Skills Certificate (SKM) Level 3. In this stage, the ELV will be classified according to the ELV condition. The classification ensures that the dismantling process flow runs efficiently although there is a variation in the condition of the supplied ELV.

The proposed improvement is that the supplied ELVs will be sorted based on their ELV category, as displayed in Table 4, where the major improvement is depicted by the red dashed box in Fig. 9. The classification of ELV is based on the percentage of automotive parts that can be reused and percentage of metal materials that can be recycled of each ELV, as shown in Table 4. Research done by Sulaiman et al. [37] was utilised to estimate the percentage rate of automotive parts that can be reused and metal resources that can be recycled from an ELV. The percentage rate for each ELV is calculated based on the quantity of items predicted to be reused and recycled from each ELV. Thus, the person in charge of categorizing the ELV must first identify the number of items from an ELV that can be reused and recycled before determining the method to dismantle the ELV based on the proportion of automotive parts that can be reused and metal materials that can be recycled. ELV in Category A will be dismantled using a partial dismantling technique, ELV in Category B will be dismantled using a selective dismantling technique, and ELV in Category C will be dismantled using a total dismantling technique.

After the dismantling process is complete, usable components will be kept for resale, metal and non-metal materials will be recycled, scheduled waste contractors will handle hazardous chemicals, and the residue will be disposed of in landfills. The proposed framework for the enhanced process flow is expected to enhance the ATF’s productivity by minimising the uncertainties in the recycling process.

Table 4 *The dismantling technique for each ELV condition*

ELV Category	Category A	Category B	Category C
Percentage of automotive parts that can be reused	0% - 30%	31% - 70%	71% - 100%
Percentage of metal materials that can be recycled	71% - 100%	31% - 70%	0% - 30%
Dismantling technique	Partial Dismantling	Selective Dismantling	Total Dismantling

Additionally, the improved process flow is beneficial to enhance ATF's productivity, because the variations in ELV condition due to uncertain ELV supply generate fluctuations in total operational cost [38]. This is because varying ELV conditions necessitate a distinct dismantling method, which has a direct impact on the total recycling cost. The ideal dismantling technique for each ELV is expected will reduce the setup time and operation time, which will lessen operational costs and enhance productivity. Besides that, choosing the most suitable dismantling technique according to the ELV condition can reduce resource waste, maximise the utilisation of labour and machinery, and ensure the dismantling process is conducted efficiently. Hence, the ATF's production system will be more systematic, as the process of dismantling will be predetermined before ELV recycling is conducted. Moreover, it is anticipated that the production schedule will be more efficient because of this enhanced process flow. Therefore, the proposed framework aims to establish standardised methods to minimise dismantling time and recycling costs by utilising the ELV classification system, despite the variation of ELV from the supplier.

4. Conclusion

This article investigates the uncertainties in Malaysia's ELV recycling operation via a case study at four ATFs in Malaysia. The sources of uncertainty in the ELV recycling operation were identified, consisting of ELV supply (M = 4.250), ELV recycling costs (M = 4.188), ATF infrastructure (M = 4.125), production planning (M = 3.875), ELV characteristics (M = 3.550), and ELV distribution network (M = 2.833). Nevertheless, the results demonstrate that the major uncertainties in the ELV recycling ecosystem are ELV supply, ELV recycling costs, and ATF infrastructure. Extended research was conducted at one of Malaysia's ATFs, and the ELV recycling process flow was observed. Based on the investigation, a conceptual framework was proposed to improve the ATF's productivity, including various improvements to the ELV disassembly line. In essence, this study is valuable for stakeholders in the ELV recycling industry, particularly in identifying the uncertainties in this business and enhancing the process flow in the ATF to boost productivity.

There are several limitations to this study, including the fact that this study only examined certain major supply chain issues. Thus, additional dimensions of supply chain uncertainty should be investigated, such as environmental uncertainty, which focuses on legislative issues, social issues, and competitive behaviour. The inclusion of other aspects of uncertainty is expected to yield a thorough understanding of supply chain uncertainty in an industry. Other than that, participants in this study are limited to stakeholders in Malaysia's ELV recycling industry, as this study aims to highlight the uncertainties in the ELV recycling sector. Hence, it is suggested that future research should expand the survey analysis to other EOL recycling industries to acquire a better understanding of supply chain uncertainty in the circular economy.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm their contribution to this article in the following manner: ***study conception and design****: Hawa Hishammuddin;* ***data collection****: Fatin Amrina A. Rashid, Hawa Hishamuddin, Mohd Radzi Abu Mansor, and Nizaroyani Saibani;* ***analysis and interpretation of results:*** *Fatin Amrina A. Rashid and Hawa Hishamuddin;* ***draft manuscript preparation:*** *Fatin Amrina A. Rashid and Hawa Hishamuddin. The authors collectively evaluated the results and approved the final version of the article.*

References

[1] J. Y. Chong, M. Z. Mat Saman, and N. H. A. Ngadiman, "End-of-life vehicles research development in Malaysia: a comprehensive review with the integrated conceptual model of innovative sustainable manufacturing elements," *J. Mater. cycles waste Manag.*, vol. 25, no. 2, pp. 698–716, 2023.

[2] Malaysian Automotive Association, "Summary of New Passenger & Commercial Vehicles Registered in Malaysia for the Year 2010 to 2020," 2021. http://www.maa.org.my/statistics.html

[3] A. H. Molla, H. Shams, Z. Harun, A. N. C. Kasim, M. K. Nallapaneni, and M. N. A. Rahman, "Evaluation of end-of-life vehicle recycling system in India in responding to the sustainability paradigm: an explorative study," *Sci. Rep.*, vol. 13, no. 1, p. 4169, 2023.

[4] Y. Li, K. Fujikawa, J. Wang, X. Li, Y. Ju, and C. Chen, "The Potential and Trend of End-Of-Life Passenger Vehicles Recycling in China," *Sustainability*, vol. 12, no. 4, p. 1455, 2020.

[5] Solid Waste and Public Cleansing Management Corporation, "National Recycling Rate," 2018.

[6] Y. C. Wong, K. M. Al-Obaidi, and N. Mahyuddin, "Recycling of end-of-life vehicles (ELVs) for building products: Concept of processing framework from automotive to construction industries in Malaysia," *J. Clean. Prod.*, vol. 190, pp. 285–302, 2018.

[7] E. Simangunsong, L. C. Hendry, and M. Stevenson, "Supply-chain uncertainty: a review and theoretical foundation for future research," *Int. J. Prod. Res.*, vol. 50, no. 16, pp. 4493–4523, 2012.
[8] N. Mohamad-Ali, R. A. R. Ghazilla, S. H. Abdul-Rashid, and A. Ahmad-Yazid, "Aftermarket survey on end-of-life vehicle recovery in Malaysia: Key findings," *J. Clean. Prod.*, vol. 211, pp. 468–480, Feb. 2019, doi: 10.1016/j.jclepro.2018.11.165.
[9] T. N. A. Raja Mamat, M. Z. Mat Saman, and V. Simic, "Key success factors in establishing end-of-life vehicle management system: a primer for Malaysia," *J. Clean. Prod.*, vol. 135, pp. 1289–1297, 2016.
[10] T. F. Go, D. Abd Wahab, Z. F. Fadzil, C. H. Azhari, and Y. Umeda, "Socio-technical Perspective on End-of-life Vehicle Recovery for a Sustainable Environment," *Int. J. Technol.*, vol. 7, no. 5, pp. 889–897, 2016.
[11] Z. M. Jawi, M. H. M. Isa, M. S. Solah, A. H. Ariffin, A. Shabadin, and M. R. Osman, "The future of end-of-life vehicles (ELV) in Malaysia–A feasibility study among car users in Klang valley," in *MATEC Web of Conferences*, 2017, vol. 90, p. 1038.
[12] Z. Harun *et al.*, "An Analysis of End-of-Life Vehicle Policy Implementation in Malaysia from the Perspectives of Laws and Public Perception," *J. Kejuruter.*, vol. 33, no. 3, pp. 709–718, 2021.
[13] L. Amelia, D. A. Wahab, C. H. C. Haron, N. Muhamad, and C. H. Azhari, "Initiating automotive component reuse in Malaysia," *J. Clean. Prod.*, vol. 17, no. 17, pp. 1572–1579, 2009.
[14] N. Mat Ropi, H. Hishamuddin, and D. Abd Wahab, "Analysis of the Supply Chain Disruption Risks in the Malaysian Automotive Remanufacturing Industry-a Case Study," *Int. J. Integr. Eng.*, vol. 12, no. 5, pp. 1–11, 2020.
[15] R. K. Yin, *Case study research and applications*. Sage, 2018.
[16] Jabatan Alam Sekitar, "Senarai Kemudahan Rawatan Automotif Berlesen (AATF)." https://www.doe.gov.my/pengurusan-bahan-berbahaya/senarai-kemudahan-rawatan-automotif-berlesen-aatf/ (accessed Mar. 31, 2023).
[17] J. Blair, R. F. Czaja, and E. A. Blair, *Designing surveys: A guide to decisions and procedures*. sage publications, 2013.
[18] Z. Yu, M. Tianshan, S. A. Rehman, A. Sharif, and L. Janjua, "Evolutionary game of end-of-life vehicle recycling groups under government regulation," *Clean Technol. Environ. Policy*, pp. 1–12, 2020.
[19] V. Simic, "Interval-Parameter Conditional Value-at-Risk Two-Stage Stochastic Programming Model for Management of End-of-Life Vehicles," *Environ. Model. Assess.*, vol. 24, no. 5, pp. 547–567, Oct. 2019.
[20] R. A. Johnson and D. W. Wichern, "Applied multivariate statistical analysis," 2002.
[21] T. V. K. Mohan and R. K. Amit, "Dismantlers' dilemma in end-of-life vehicle recycling markets: a system dynamics model," *Ann. Oper. Res.*, vol. 290, no. 1, pp. 591–619, 2020.
[22] C. Zhang and M. Chen, "Designing and verifying a disassembly line approach to cope with the upsurge of end-of-life vehicles in China," *Waste Manag.*, vol. 76, pp. 697–707, 2018.
[23] K. Govindan and H. Gholizadeh, "Robust network design for sustainable-resilient reverse logistics network using big data: A case study of end-of-life vehicles," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 149, p. 102279, 2021.
[24] H. Hao, Q. Zhang, Z. Wang, and J. Zhang, "Forecasting the number of end-of-life vehicles using a hybrid model based on grey model and artificial neural network," *J. Clean. Prod.*, vol. 202, pp. 684–696, 2018.
[25] S. Ahmed, S. Ahmed, M. R. H. Shumon, M. A. Quader, H. M. Cho, and M. I. Mahmud, "Prioritizing strategies for sustainable end-of-life vehicle management using combinatorial multi-criteria decision making method," *Int. J. Fuzzy Syst.*, vol. 18, no. 3, pp. 448–462, 2016.
[26] T. N. A. Raja Mamat, M. Z. Mat Saman, S. Sharif, V. Simic, and D. Abd Wahab, "Development of a performance evaluation tool for end-of-life vehicle management system implementation using the analytic hierarchy process," *Waste Manag. Res.*, vol. 36, no. 12, pp. 1210–1222, 2018.
[27] S. Karagoz, N. Aydin, and V. Simic, "End-of-life vehicle management: a comprehensive review," *J. Mater. Cycles Waste Manag.*, vol. 22, no. 2, pp. 416–442, 2020, [Online]. Available: https://doi.org/10.1007/s10163-019-00945-y
[28] Y. Yang, J. Hu, Y. Liu, and X. Chen, "Alternative selection of end-of-life vehicle management in China: A group decision-making approach based on picture hesitant fuzzy measurements," *J. Clean. Prod.*, vol. 206, pp. 631–645, 2019.
[29] C. Zhang and M. Chen, "Prioritising alternatives for sustainable end-of-life vehicle disassembly in China using AHP methodology," *Technol. Anal. Strateg. Manag.*, vol. 30, no. 5, pp. 556–568, May 2018.
[30] K. Chakraborty, S. Mondal, and K. Mukherjee, "Analysis of the critical success factors of automotive engine remanufacturing in India," *Uncertain Supply Chain Manag.*, vol. 5, no. 3, pp. 215–228, 2017.
[31] V. Nair, "New method to manage abandoned vehicles," Kuala Lumpur, 2021. [Online]. Available: https://www.thestar.com.my/metro/metro-news/2021/11/22/new-method-to-manage-abandoned-vehicles
[32] J. L. Rickli and J. A. Camelio, "Multi-objective partial disassembly optimization based on sequence feasibility," *J. Manuf. Syst.*, vol. 32, no. 1, pp. 281–293, 2013.

[33] M. L. Bentaha, A. Dolgui, O. Battaïa, R. J. Riggs, and J. Hu, “Profit-oriented partial disassembly line design: dealing with hazardous parts and task processing times uncertainty,” *Int. J. Prod. Res.*, vol. 56, no. 24, pp. 7220–7242, 2018.
[34] E. Tuncel, A. Zeid, and S. Kamarthi, “Inventory Management in Multi-Product, Multi-Demand Disassembly Line using Reinforcement Learning,” in *Proc. Int. Conf. Ind. Engine. Istanbul, Turkey*, 2012, pp. 1866–1873.
[35] M. Chen and F. Zhang, “End-of-life vehicle recovery in China: consideration and innovation following the EU ELV directive,” *JOM*, vol. 61, no. 3, pp. 45–52, 2009.
[36] N. Nordin, B. Md Deros, D. Abdul Wahab, and M. N. Ab Rahman, “Validation of lean manufacturing implementation framework using Delphi technique,” *J. Teknol.*, vol. 59, no. 2012, pp. 1–6, 2012.
[37] M. S. Sulaiman, D. Abd Wahab, Z. Harun, H. Hishamuddin, N. K. Khamis, and M. R. A. Mansor, “Preliminary study on End-of-Life Vehicles recycling rate for Malaysia,” *Energy Reports*, vol. 9, pp. 235–246, 2023.
[38] H. Liao, Q. Deng, and N. Shen, “Optimal remanufacture-up-to strategy with uncertainties in acquisition quality, quantity, and market demand,” *J. Clean. Prod.*, vol. 206, pp. 987–1003, 2019.