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# End-of-Life Vehicle Recovery Framework: An Industry Perspective on Auto Parts Reuse, Recycling, and Remanufacturing in Malaysia

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**Abstract**
The rise of end-of-life vehicles (ELVs) in Malaysia highlights the urgent need for a sustainable recovery industry centered on reuse, recycling, and remanufacturing. Ineffective ELV management exacerbates waste generation, adversely affecting Sustainable Development Goal (SDG) 12 on responsible consumption and production. This study evaluated the current state of ELV reuse, recycling, and remanufacturing in Malaysia by selecting ten companies and employing a qualitative approach. Data were gathered through semi-structured interviews with industry stakeholders, supported by qualitative content analysis conducted in collaboration with a research team and industry experts. Responses were triangulated with direct observations during site visits. Key enablers for a sustainable framework were identified, including design strategies, adequate facilities, skilled labour, and efficient processes. The findings culminated in a sustainable ELV recovery framework emphasizing operational and stakeholder-driven perspectives. This framework is a roadmap for policymakers and industry players to align with regional sustainability goals.

**Keywords**
End-of-life vehicle (ELV); reuse and recycle; auto part remanufacturing; sustainability; ELV recovery.

## Introduction

The rapid rise in end-of-life vehicles (ELVs) in Malaysia underscores the urgent need to establish a sustainable recovery industry centered on reuse, recycling, and remanufacturing. These three pillars are closely interconnected, as reuse and recycling not only reduce waste but also supply valuable materials for the remanufacturing process, which extends the lifecycle of auto parts. Remanufacturing, in turn, provides significant economic and environmental benefits by conserving resources and minimizing waste, contributing to a more sustainable ELV recovery ecosystem (Li et al., 2014). By 2040, Malaysia is expected to generate approximately 500,000 ELVs annually, driven by a market saturation of 12 million passenger vehicles by 2030 (Azmi & Tokai, 2017). This projected increase raises serious environmental concerns, particularly in managing hazardous materials from improper ELV disposal (Vermeulen et al., 2011), further emphasizing the need for an integrated reuse, recycling, and remanufacturing approach.

Globally, countries have implemented stringent regulations to make ELV reuse and recycling mandatory. The EU, for instance, set ambitious targets for "reuse and recovery" and "reuse and recycling" of 95% and 85%, respectively, on 1 Jan 2015. Similar targets were set in Japan (Vermeulen et al., 2011). China began upgrading ELV recycling in 2008 when they found that remanufacturing technology, equipment, and market access for remanufactured products were the essential challenges. In Japan, the proper treatment of ELVs, the

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ELV Recycling Act, entered into force in 2005 (Sakai et al., 2014), while Korea established the Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles. In contrast, Malaysia's ELV practices remain less structured, with most vehicles being funneled into auto part dealers, contributing significantly to waste generation (Othman et al., 2021). ELVs are divided into two categories i.e., premature ELVs that come from retired and unusable vehicles or vehicles that can no longer be used, and the natural ELVs, i.e., vehicles no longer used after failing inspection, failure of owners to renew road tax, high cost of repair, or unavailability of spare parts (Raja Mamat et al., 2016).

The automotive industry in Malaysia is also known as the catalyst for other related industries, such as metal fabrication, rubber, and plastic, as well as the electric and electronic industries. The industry contributes about RM40 billion or 4% of Malaysia's GDP, with a workforce of close to 700,000 people, an estimated 53,000 aftermarket establishments, and more than 600 parts and components suppliers (Ministry of International Trade and Industry ([MITI], 2020). According to Mohamad-Ali et al. (2019), 5,000 used parts are imported per month, and most of these parts are imported from China and Taiwan to support the demand for spare parts in Malaysia. Automotive components that are presently being remanufactured and reused include clutches, brake shoes, engine blocks, starters, alternators, water pumps, and carburetors (Amelia et al., 2009).

As Malaysia strives to position itself as a remanufacturing hub in ASEAN by 2030 under the National Automotive Policy 2020 (NAP 2020), it is crucial to establish a clear ELV recovery framework. This would align with global sustainability goals, particularly the Sustainable Development Goal (SDG) 12, which focuses on responsible consumption and production, including the recovery and recycling of auto parts and ELVs. Hence, this study aims to assess the current state of the ELV reuse, recycling, and remanufacturing industry in Malaysia, emphasizing the perspectives of industry stakeholders. It highlights their insights into the capabilities, processes, and design strategies required to develop a sustainable ELV recovery framework.

The remainder of this paper is organized as follows. An overview of the literature related to the recovery strategy, automotive aftermarket industry, design strategy, and ELV studies is presented in Section 2. The methodology adopted in this study is presented in Section 3. The results are presented in Section 4 and the discussion in Section 5. The conclusion drawn from the study is summarized at the end of this paper.

## Literature Review

### Recovery Strategy

Recovery refers to the process of collecting products at the end of their use stage, disassembling, sorting, and cleaning them to be utilized in a future cycle of the product. End-of-life product recovery strategies include remanufacturing, repairing, reconditioning, cannibalization, redesigning, refurbishing, and recycling (Jawahir & Bradley, 2016). The remanufacturing process comprises a detailed procedure of disassembly, cleaning, inspection, restoration, reassembly, and finally, testing before the product is ready to be shipped (Matsumoto et al., 2016). The code of practice in Malaysia involves a specific definition established under the Malaysian Standard for motor vehicle aftermarket – repair, reuse, recycle, and remanufacture (4R) for parts and components.

In this context, reuse is defined as any operation by which parts and components of vehicles are used for the same purpose for which they were conceived, while recycling is defined as the process of segregating non-usable parts or components for material recovery. Meanwhile, remanufacture is defined as the process of restoring existing parts or components to "as good as new" condition using a standardized industrial process in line with specific technical specifications (Department of Standards Malaysia, 2018). In the realm of auto parts recovery, insights from Mohamad-Ali et al. (2019) underscore the need for specialized tooling to handle ELV components. Lee et al. (2023) conducted a life cycle assessment (LCA) comparing remanufactured turbochargers to newly manufactured ones. Their analysis revealed that remanufacturing achieved a significant energy saving of 83.9%. Meanwhile (Litwin et al., 2024) proposed a method for optimizing the remanufacturing process flow of brake callipers using the system dynamics (SD) approach. This model serves as a foundation for simulating and analysing production flow, enabling the identification of bottlenecks and inefficiencies.

Moreover, the design part must facilitate material separation, addressing challenges such as material non-durability, intricate joining methods hindering disassembly, and costly product features that impede recovery, as highlighted by Fegade et al. (2015). These challenges underscore the vitalness of a comprehensive integration of the Design for Remanufacturing (DfRem) principles and practices. Without such integration, Malaysia's auto parts reuse and recycling sector cannot harness its full potential toward sustainable remanufacturing practices.

### Aftermarket Industry in Malaysia

The automotive industry has largely contributed to the Malaysian economy in the last three decades. From the establishment of Malaysia's first national car, Proton in 1983, followed by Perodua (Perusahaan Edaran Otomobil Kedua) in 1993, both companies are still producing new vehicles to fulfil the local and export market demand. Since then, the local automotive industry has had more than 20 manufacturing and assembly plants in the country, producing passenger and commercial vehicles, as well as motorcycles and scooters.

Based on records, more than 60,000 abandoned vehicles are still registered throughout the country (NST,2018). Abandoned vehicles, also known as ELVs, can normally be found on the roadside of residential areas, shop lots, and parking lots in malls. Inadequate management of ELV recovery will contribute to the escalation of waste generation, as well as posing a major challenge for the management authorities (Li et al., 2014). The ELV recovery stage in the automotive industry may be seen as one of the strategies to reduce waste materials by reusing, recycling, and remanufacturing vehicle components (Özceylan et al., 2017). Parts such as engines, transmissions, door mirrors, audio equipment, and others that are deemed high in demand, in good condition, and of high value will be dismantled. The valuable components are also remanufactured to produce new products. Remanufacturing is considered one of the most effective strategies for lessening the adverse effects on the environment. It is typically known as a substantial part of the entire manufacturing industry and one of the examples of a circular economy approach (Kalverkamp & Raabe, 2018). However, the difficulty in obtaining the spare parts components for remanufacturing is the highest contributor to the supply chain disruption risks (Ropi et al., 2020). Furthermore, limited case studies or surveys are documented in the present ELV recovery industry practices (Karagoz et al., 2020).

### Design for Remanufacturing (DfRem)

DfRem plays a crucial role in unlocking the potential for sustainable remanufacturing practices worldwide. DfRem encompasses a spectrum of principles, methodologies, and practices meticulously tailored to optimize product design, thereby facilitating seamless remanufacturing processes. This optimization not only extends product lifecycles but also substantially reduces environmental impact. However, the ambiguity surrounding the definition of remanufacturing, as highlighted by (Ijomah et al. (2007), presents a significant challenge. Remanufacturing becomes especially intricate without a predefined end-of-life strategy during product design, as emphasized by (Fegade et al. (2015). Various design strategies are instrumental in enabling remanufacturability, including design for assembly (Raja Ghazilla et al., 2015), design for disassembly (Battaïa et al., 2018), design for cleaning (Abu et al., 2014; Umeda, 1999), design for inspection (Genta et al., 2018; Stolt et al., 2017), design for recycling (Gerrard & Kandlikar, 2007; Hiratsuka et al., 2014), and design for reuse (Amelia et al., 2009). Additionally, integrating modular product design and end-of-life strategies, as identified by Sakundarini et al. (2015), is pivotal in minimizing environmental impact during product retirement.

### End-of-life Vehicle (ELV) recovery framework

The development of ELV recovery frameworks has been extensively explored in the literature over the years. Go et al. (2010) proposed framework for end-of-life vehicle recovery in Malaysia that emphasizes designing automotive components for disassembly, utilizing genetic algorithms to optimize disassembly sequences, and enhancing recovery through effective disassembly strategies, ultimately supporting reuse and recycling targets. Azmi et al. (2013) proposed a framework for managing ELV recycling systems in Malaysia, addressing environmental and safety concerns.

Subsequently, Go et al. (2016) assessed the socio-technical knowledge of the Japanese and Malaysian communities to ensure effective ELV recovery through reuse and remanufacturing. Yusop et al. (2016) surveyed the actual implementation of automotive remanufacturing in Malaysia, identifying critical challenges such as inadequate production planning, limited infrastructure, distribution networks, and ineffective inventory management. In response to these challenges, Ropi et al. (2020) emphasized the need for advanced Industry 4.0 practices and skilled labour to enhance remanufacturing efficiency. Similarly, Ngu et al. (2020) called for proactive measures, recommending real-time industry surveys and research programs to address skill shortages.

Golinska-Dawson et al. (2021) presented a two-layered framework for responsible resource management in remanufacturing, defining five maturity levels for water, emissions, energy, and materials, along with a self-assessment tool for rapid evaluations. Aguilar Esteva et al. (2021) integrated circular economy principles, emphasizing waste reduction and resource recovery throughout the product lifecycle. Harun et al. (2021) highlighted the low public awareness and acceptance of ELV recovery initiatives in Malaysia, stressing the need for establishing firm standards to mitigate potential environmental, health, and economic issues. (Jamaluddin et al. (2022). underscored the importance of addressing product maturity, financial viability, and labour availability to ensure ELV recovery success. Further advancements were proposed by Karunarathna and Gamage (2022), who emphasized the integration of defined remanufacturing processes and advanced technologies while (Wang et al., 2023) introduced a methodological system for recycling scrapped automobiles, identifying factors at both micro and macro levels that influence automobile recycling and providing a foundation for empirical frameworks. Most recently, (Pizoń et al., 2024) discusses the importance of process analysis and simulations in decision-making regarding the automation of internal logistics. This approach provides a framework for companies to evaluate the potential benefits of implementing Autonomous Mobile Robots (AMR) in automotive remanufacturing operations.

## Method

A qualitative approach was adopted to achieve the objectives of this study and gain valuable insights. The researchers collaborated with the Malaysia Automotive Recycler Association (MAARA); a specialized non-profit association dedicated to members of the auto parts recycling industry in Malaysia. The interviews and discussions were carried out following these steps:

1. Questionnaire Development:
    - Performed a comprehensive literature review to develop focused questions addressing reuse, recycling, remanufacturing processes, and design strategies.
    - Consulted five subject matter experts (SMEs) for feedback, including three academic experts and two industry practitioners.
    - Revised and finalized the questionnaire based on SMEs inputs.
2. Industry Engagement:
    - Held meetings with industry representatives to schedule site visits and refine the semi-structured questionnaire.
3. Site Visits and Data Collection:
    - Conducted visits to ten companies located in Port Klang, Selangor, and Ipoh, Perak.
    - Gathered data through interviews, participatory observations, and document reviews from June to July 2022.
    - Interviews lasted 1 to 2.5 hours, depending on the company's capacity and contributions.
4. Data Analysis:
    - Compiled responses, field notes, and visual data from observation (picture and videos). Record and measure the quantitative question in numbers, average and percentage for Part 1A,2C and Part 3.
    - Performed qualitative content analysis, especially for open-ended responses Part 4
    - Validated findings through discussions with a research team comprising MAARA members, academia, and industry representatives.
5. Stakeholder Review and Refinement:
    - Presented results to stakeholders in a final meeting.
    - Incorporated feedback to refine findings and develop the proposed ELV recovery framework.

## Results

The questionnaire was divided into four parts, starting with the company overview in section A, focusing on the company background and section B, on business operation. Part 2 comprises a process overview, while Part 3 covers design strategy awareness. The last part of the questionnaire is Part 4, comprising subjective questions with an open-ended format to acquire additional opinions and experience related to the auto part recovery industry in Malaysia, including reuse, recycling, and remanufacturing activities. Table 1 shows the description of each section in the semi-structured questionnaire as a guide during the site visit sessions.

The analysis of Part 4, which included open-ended subjective responses, was conducted through a qualitative content analysis process. The compiled findings were then reviewed and discussed with a research team comprising industry experts from MAARA, academia, and company representatives to validate the data and ensure it reflected current industry conditions. This review process also allowed for the extraction of additional insights or details that may have been missed during the site visits. By triangulating the questionnaire responses with direct observations, the analysis provided a comprehensive and robust understanding. Finally, the results were presented to stakeholders in a final meeting, where further discussions led to the refinement of the findings, forming the basis for the development of the framework detailed in the following section.

Table 1
Description of semi structure question

| Section | Description | |
|---|---|---|
| **Part 1: Company Overview** | (A) Company background | (B) Business operation |
| | Information on company's background such as respondent name, designation, company name, years of experience, location, scope of business | Details on the business operation such as number of workers, number of shifts, production capacity and standard or management system applied |
| **Part 2: Process overview** | Interview and observe company's existing process and activity (compare with remanufacturing steps to get the relationship) | |
| **Part 3: Design strategy** | Assess company's awareness on design for remanufacturing strategy from their perspectives | |
| **Part 4: Subjective questions** | Additional opinion and experiences-based question related to auto part reuse, recycling, and remanufacturing activities | |

## Part 1 (A): Company Background

The unit of analysis in this study is primarily the organization, as the focus is on the company's operations. However, to provide deeper insights into the expertise influencing these operations, the individual experiences of key personnel, typically owners or directors, were also considered. The "years of experience" data shown in Figure 1 represents the individual experiences of the respondents, who are decision-makers and leaders directly involved in the auto parts and ELV business activities, including day-to-day company operations, such as reuse, recycling, and remanufacturing. The respondents are fully responsible for the processes, issues, and challenges in running their business. They possess significant knowledge and skills, with an average of 23 years of experience. They possess significant knowledge and skills, with an average of 23 years of experience, making their insights and feedback during interviews and site visits particularly valuable for this study.

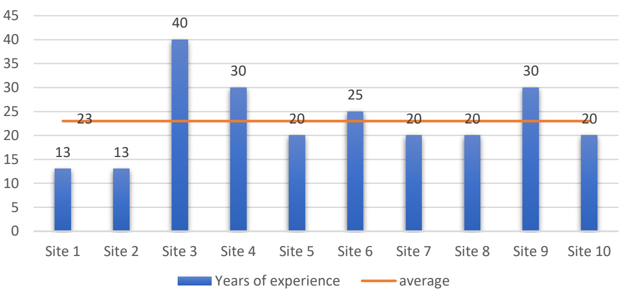


Fig. 1. Respondent's years of experience

Ten companies were purposively selected to participate in the study, focusing on those located in key industrial areas of Port Klang, Selangor, and Ipoh, Perak. These regions were chosen due to the significant presence of well-established companies in the auto parts recovery industry, as identified through membership data from the Malaysian Automotive Recyclers Association (MAARA). The selection criteria included the companies' extensive operational experience in handling ELVs and remanufacturing processes, as well as their willingness and availability to share their experiences. This purposive sampling approach ensured that the research captured in-depth, practical knowledge directly from industry leaders actively engaged in the field. By selecting experienced and cooperative companies, the study was able to achieve its objectives of exploring reuse, recycling, and remanufacturing activities within the automotive parts recovery sector.

Table 2 outlines the company's scope of business and the respondents' designations. It shows that the industry is largely shaped by the expertise and leadership of these individuals, which directly reflects the organization's operational capacity and strategic direction. The respondents are fully responsible on the processes, issues, and challenges in running their ELV recovery business. During the site visit, the respondents were very supportive and answered all the questions based on their experience and knowledge.

## Part 1 (B): Business Operation

Business operation in this study focuses on the existing capabilities of each company based on the number of workers, number of shifts, production capacity, and standard or management system applied. Table 3 summarizes the business operation of each company. Overall, the interviews revealed that all companies are operating under the category of Small and Medium Enterprises (SMEs; SME Corp. Malaysia, 2020). The

Table 2
Company background

| Company | Scope of business: | Respondent designation |
|---|---|---|
| **Site 1** | Automotive and Vehicles Sales, Rental, Spare parts & service, Material handling | Director |
| **Site 2** | Selling (import/ export) spare part automotive | CEO |
| **Site 3** | Automotive and Vehicles wholesale of used engine and spare part (Import export) | MD & Asst manager |
| **Site 4** | Automotive and Vehicles Trading used auto part, spare part, and other materials | Director |
| **Site 5** | Wholesale of metal & non-metal waste and scrap material for recycling (used Automotive and Vehicles parts) | Business owner & admin |
| **Site 6** | Automotive and Vehicles Import export (used auto parts) | CEO |
| **Site 7** | Import and export of used parts dealer in trucks, buses, marine and general merchandise. | Director |
| **Site 8** | Import and Export of Back hoes, Wheel Loaders, Road Rollers, Bull Dozers & Forklift., Prime Movers, Trucks, Tankers & Trailers, Marine Boats, Excavators & Crane., Engine, Parts & Body Parts, Air Compressors & Welding Sets, Generator sets | Director |
| **Site 9** | Auto workshop, repair & recycle | Director |
| **Site 10** | Importer, Exporter & Distributor of all kinds of Auto Spare Parts & Accessories | Director |

Table 3
Summary of ELV recovery company operation

| | **Site 1** | **Site 2** | **Site 3** | **Site 4** | **Site 5** | **Site 6** | **Site 7** | **Site 8** | **Site 9** | **Site 10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Business category** | SME | SME | SME | SME | SME | SME | SME | SME | SME | SME |
| **Total number of workers** | 120 | 30 | 50 | 21 | 11 | 26 | ±12 | ±12 | ±3 | 7 |
| **Numbers of production line workers** | ±50 | ±20 | ±45 | ±10 | ±10 | ±10 | 6 | ±10 | ±5 | <10 |
| **Production capacity per month:** | On demand/ project based | On demand | On demand | Import 7–8 container/ month | 1 container / month | 7-8 container / month | On demand | On demand | On demand | On demand |
| **Operation Hours** | 1 shift Sunday -closed | 1 shift Mon–Sat 9 am–6 pm | 1 shift | 1 shift Mon–Sat 9 am–6 pm | 1 shift Mon–Sat 9 am–6 pm | 1 shift Mon–Sat 9 am–6 pm | 9 am–6 pm | 1 shift | 1shift | 1shift |
| **Any standard or management system applied** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

definition of SMEs in Malaysia was established by the SME Corporation Malaysia (SME Corp. Malaysia), which is the central coordinating agency (CCA) under the Ministry of Entrepreneur and Cooperatives Development (MECD). MECD coordinates the implementation of development programs for SMEs across all related ministries and agencies. It acts as the central point of reference for research and data dissemination on SMEs and entrepreneurs, as well as providing business advisory services for SMEs and entrepreneurs throughout the country.

### Part 2(A): Process Overview

The respondents were asked about their activity on each process based on the remanufacturing process, as stated in previous studies (Conseil Européen de Remanufacture, 2017; Hammond et al., 1998; Matsumoto et al., 2016; Östlin, 2008; Shu & Flowers, 1993). To be more precise for the local ELV recovery industry, this process also refers to the Malaysia Standard MS 2697:2018 motor vehicle aftermarket repair – repair, reuse, repair and remanufacture (4R) of parts and components (Department of Standards Malaysia, (2018). The generic process flow is illustrated in Figure 2, which shows the concise steps involved. This has been used as a guideline during the site visits and observations at each company. Table 4 provides a summary of each company process flow based on site visit observation and respondents' explanations.

### 2(A)(i) Cores received

From the explanations and observations during the site visits, most of the companies received their cores (which is auto parts from end-of-life vehicle) regularly from imported ELVs and local sources despite some challenges due to government policy on imported ELVs. Only one company did not constantly receive and manage cores because the nature of business is only a car repairing workshop. The cores received are classified into three categories: half-cut, front-cut, and set of parts, such as the engine part only.

### 2(A)(ii) Sorting

Most of the companies performed the sorting of their cores very well according to core types, sizes, and categories. When asked how they managed the core during arrival, most of them stated that the cores were managed manually using a forklift or lifting equipment operated by workers. No specific intelligent machine-like robotic system is available for lifting or automatic conveyance for sorting and transporting the cores. However, the manual sorting activities were managed properly by experienced workers to utilize the factory's space and facilities like racking, bucket, and stacking.

### 2(A)(iii) Disassembly

Once the received cores are sorted according to types, sizes, and categories, they will be segregated into good and damaged cores. This process is also done manually based on the operators' knowledge and

Table 4
Summary of process overview

| | Company process overview | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Process flow** | Site 1 | Site 2 | Site 3 | Site 4 | Site 5 | Site 6 | Site 7 | Site 8 | Site 9 | Site 10 |
| **Receive core** | / | / | / | / | / | / | / | / | / | / |
| **Sorting** | / | / | / | / | / | / | / | / | N | / |
| **Disassembly** | / | / | / | / | / | / | / | / | N | / |
| **Cleaning** | / | N | N | N | N | N | N | /* | N | N |
| **Part replacement, repair & restoration** | /* | /* | N | N | N | N | N | /* | /* | N |
| **Inspection and testing** | /* | /s | /s | N | N | /s | / | / | / | / |
| **Assembly/reassembly** | / | N | N | N | N | N | N | / | / | N |
| **Final inspection and testing** | / | N | N | N | N | N | N | / | / | N |
| **Painting** | / | N | N | N | N | N | N | / | /* | N |
| **Warranty preparation** | 6month | 2-3weeks | NW | 1month | 2week | 2week | NW | /* | NW | NW |
| **Labelling and packaging** | /* | /* | /* | /* | /* | /* | /* | /* | N | /* |
| **Shipping** | /* | /* | /* | /* | /* | /* | /* | /* | N | /* |
| **Remark:** | mark with (/) = The company **carried out the activity** (explained by the respondent during interview and observed by author on site) | | | | | | | | | |
| | mark with (N) = The company did **not carry out the activity** (explained by respondent during interview and observe by author on site) | | | | | | | | | |
| | mark with (/*) = The company carried out the activity **depending on customer demand** (explained by respondent during interview and observe by author on site) | | | | | | | | | |
| | mark with (/s) = The company **carried out the inspection activity at supplier site** (explained by respondent during interview) | | | | | | | | | |

Table 5
Summary of auto part/ELV reuse, recycling, and remanufacturing process handling

| **Standard process flow** | **site 1** | **site 2** | **site 3** | **site 4** | **site 5** | **site 6** | **site 7** | **site 8** | **site 9** | **site 10** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Core/used parts management (receive part)** | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) |
| **Sorting** | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) | Semi Auto (forklift) |
| **Disassembly** | Semi Auto (tools) | Semi Auto (tools) | Semi Auto (tools) | Semi Auto (tools) | Semi Auto (tools) | NA | NA | Semi Auto (tools) | NA | Semi Auto (tools) |
| **Cleaning** | Manual | NA | NA | NA | NA | NA | NA | Manual | NA | NA |
| **Part replacement, repair & restoration** | Manual & Semi Auto (welding) | NA | NA | NA | NA | NA | NA | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) | NA |
| **Inspection and testing** | Manual & Semi Auto (welding) | NA | NA | NA | NA | NA | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) |
| **Assembly** | Semi Auto (tools) | NA | NA | NA | NA | NA | NA | Semi Auto (tools) | NA | NA |
| **Final inspection and testing** | Manual & Semi Auto (welding) | N/A (up to user/ workshop) | NA | NA | NA | NA | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) | Manual & Semi Auto (welding) |
| **Painting** | Semi Auto (spray) | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Warranty preparation** | Manual | Manual | NA | Manual | Manual | Manual | NA | Manual | NA | NA |
| **Labelling and packaging** | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| **Shipping** | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) | Semi auto (forklift) |
| **Remark:** | mark with (NA) = The company did **not carry out the activity** | | | | | | | | | |
| **Description:** | **Manual:**<br>the process was carried out by workers with some simple tools, equipment, or device. (Ex: cleaning using hose with air pressure)<br>**Semi auto:**<br>the process was carried out by workers with machine aided. (Ex: lifting the core using forklift)<br>**Automatic:**<br>workers only involve in the programming or controlling of the machine, tools, equipment remotely. (Ex: Robotic, IoT) | | | | | | | | | |

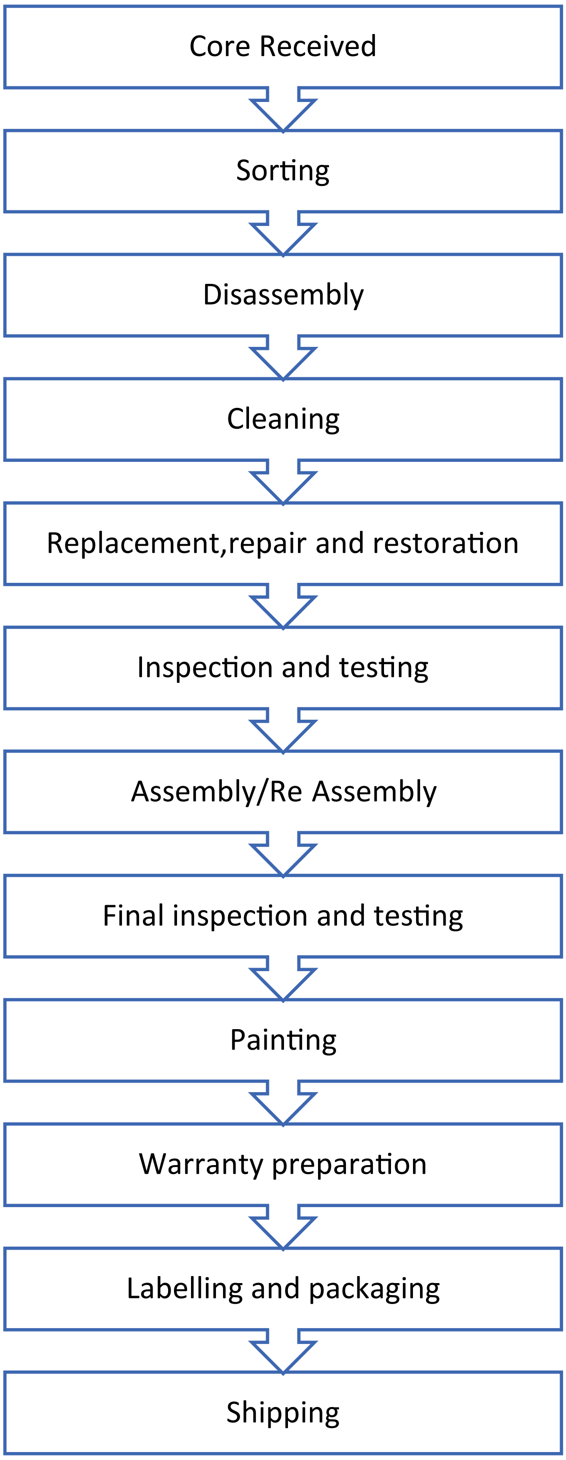


Fig. 2. Generic remanufacturing process

experiences, after which the cores are transferred to the disassembly section. The workers will disassemble the core manually using common tools, such as screwdrivers, spanners, hammers, air wrenches, and some special tools to ease the process.

#### 2(A)(iv) Cleaning

Only two companies are involved in the cleaning process. This is also based on customer requirements. The cores are cleaned at designated areas using a specific degreaser and water. This step is conducted manually by the operators. Some respondents noted that they did not perform the cleaning process as they felt that the process might affect the quality of the cores.

#### 2(A)(v) Part replacement, repair, and restoration

This step is conducted by three companies. The process will be conducted per the request of the customer. The company will obtain a consent form from the customer prior to any replacement, repair, or restoration of the cores.

#### 2(A)(vi) Inspection and testing of the cores

This step is mostly performed manually by the operators. Some of the companies arranged for their trained workers to conduct inspection and testing of the cores at the supplier's site. The workers will only select good-quality cores to be brought back to their company.

#### 2(A)(vii) Assembly (or reassembly)

This activity is conducted once the part has been replaced, repaired, or restored according to the conditions requested by the customers. Only three companies conduct the reassembly process.

#### 2(A)(viii) Final inspection and testing

This activity is performed by three companies. They are the same companies that conduct part replacement, repair, and restoration. Inspection and testing are performed on-site by trained and experienced workers upon completion of component replacement or core repair.

#### 2(A)(ix) Painting

One company conducts the painting activity. The cores are painted after repair and restoration to differentiate them from the ones that have yet to undergo the repair and restoration process.

#### 2(A)(x) Warranty

From the ten companies, only five reported that they provide a warranty based on terms and conditions agreed upon by their customers. The warranty period typically ranges from 1 to 2 weeks, but this can vary depending on the component type and fixing method used by the customer. In some cases, components may receive up to 6 months of warranty coverage. If functional issues arise, the company will replace the core according to the agreed-upon terms and conditions between both parties.

### 2(A)(xi) Labelling and packaging

This activity is carried out manually. Packaging depends on the types and size of the core, while shipping is conducted based on customer requirements. It is either through self-pickup or transportation by third parties arranged by the company.

### Part 2(B): Process handling

To assess the facilities and capabilities in handling each process, the respondents were asked on how they perform each process, whether it is done manually, semi-automated, or automated. Based on the respondents' explanations and observations on site, no process was performed using fully automated systems.

### Part 2(C): Skilled workers

Overall, the respondents from all ten companies agree that their workers must have specific skills and competencies in handling the ELV processes or activities. The skills required of the workers are welding, repairing, sorting, disassembly, and engine testing, as illustrated in Figure 3. The disassembly skill (55%) is the highest skill needed, as mentioned by 6 of 10 respondents during the interview session. Based on observations, the disassembly process was done manually, and sometimes, the operator needed to use special tools to disassemble the cores.

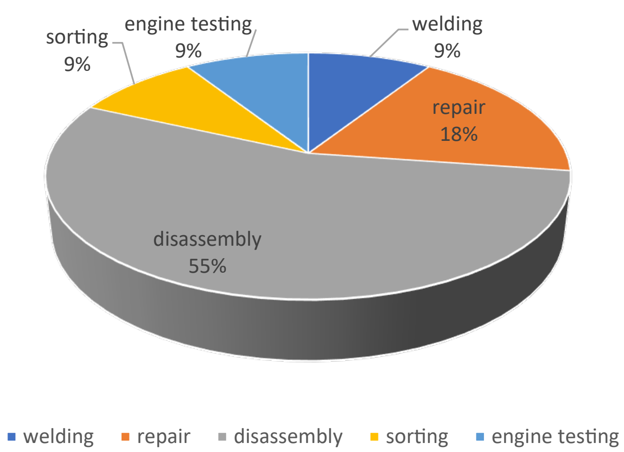


Fig. 3. Type of skills needed

### Part 2(D): Facilities

Besides the process overview, the existing facilities of each company in the ELV recovery industry were also observed to assess their capabilities in conducting daily operations to support the industry ecosystem. The findings show that most companies have well-maintained warehouses with adequate space to store ELV parts and components and have designated areas for each item. Some companies even have huge warehouses with good housekeeping practices. However, some warehouses may face challenges in allocating space for incoming cores. Adequate material handling equipment, including forklifts of varying weight capacities, hand trucks, and trolleys, were observed. Most of the companies have specialized tools for disassembly activities. The administrative section of most companies is in comfortable office buildings. The companies are aware of the compliance with environmental regulations, such as Environmental Quality (Scheduled Waste) Regulations 2005, to manage hazardous waste like spent lubricating oil and spent hydraulic oil collected from some parts of ELV cores.

### Part 3: Design Strategy Awareness

The results from the site visits indicate that all respondents from the ten companies agree on the importance of design strategy to their business. As shown in Figure 4, the most important design strategies indicated by 100% are Design for Disassembly, Design for Ease of Assembly, Design for Environment, Design for Recycling and Design for Reuse, followed by Design for Remanufacturing, Design for Inspection, and Design for Cleaning. Only two companies (20%) regard Design for Cleaning to be important as they provide cleaning activities based on customer requirements. Meanwhile, Design for Testing is shown to be the least important, with only one company agreeing on its importance. This is due to less testing done by most of the companies.

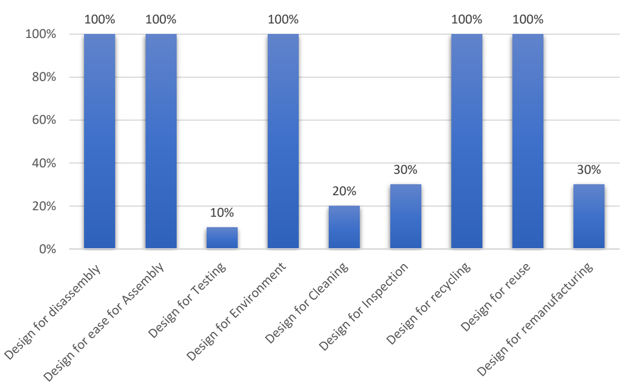


Fig. 4. The importance of design strategy

Most companies agree that the design strategies for disassembly, ease of assembly, recycling, reuse, and environment are important, as most of their core business activities involve reuse and recycling. Design for Remanufacturing is considered important by a small number of respondents (30%) since most companies did not carry out full remanufacturing activities.

Overall, the results show that companies are aware of the importance of design strategies. However, the importance of each design strategy varies depending on the operations and purposes of the respective companies. For example, they only conduct testing, cleaning, and inspection for specific parts or requirements. Although they are not directly involved in the core product design, their input is valuable because it reflects their experience in handling auto part recovery processes, especially during the disassembly part of reuse, recycling, and remanufacturing purposes. Product design is crucial for the efficient recovery of ELVs, and awareness of design strategies is essential for improving ELV recovery activities in Malaysia.

### Part 4: Subjective Questions

In the final interview session at each company, some relevant open-ended questions were asked to the respondents, such as what challenges they faced as an ELV reuse, recycling, and remanufacturing company. They were also asked to address or share issues that will help improve the ELV recovery industry in Malaysia. The overall data and information were presented during the final meeting involving all stakeholders, where the findings and discussions were summarized leading to the development of the framework detailed in the discussion section. Here is the list of some issues highlighted by the respondents:

1. Suggestion to review the ELV tax import policy and receiving inspection method.
2. They are not clear on the auto parts scrap that are banned from the import guidelines (refer to the mixing of hazardous waste and ELV parts and components).
3. Labor shortage, especially skilled local workers.
4. Proper ELV recovery business strategy or policy to gain better revenue from this industry as well as to enhance Malaysia's networking with ELV recovery stakeholders from Europe, the Middle East, and ASEAN.

## Discussion

Based on this research, a crucial relationship between key elements such as design strategy, auto part manufacturers or original equipment manufacturer (OEM), and auto part reuse, recycling, and remanufacturers has been identified. The sustainable ELV recovery framework for Malaysia developed from this research is illustrated in Figure 5. The emphasis on the importance of an integrated reuse/recycle center, which serves as a central hub to streamline operations, ensures that components flow efficiently between manufacturers, remanufacturers, and end users. Key factors like adequate facilities, strategic locations, efficient processes, and skilled workers are identified as critical enablers of this framework. These elements ensure that the system not only operates smoothly but also aligns with sustainability goals. However, the interviews high-

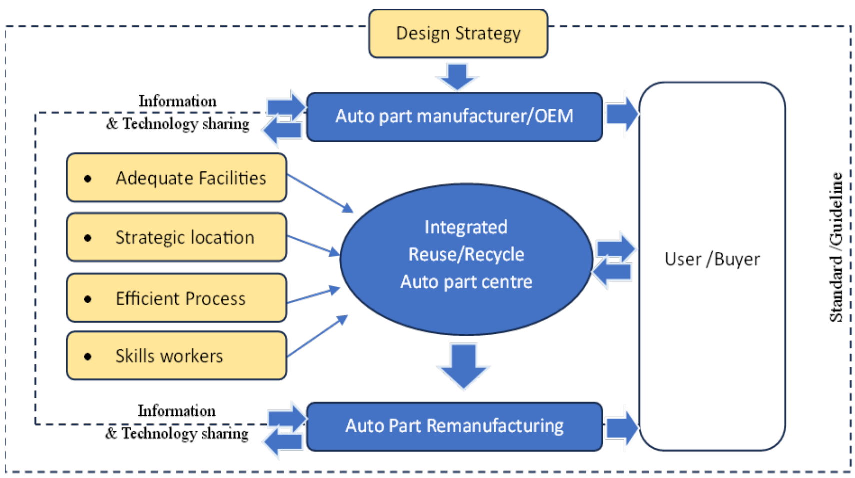


Fig. 5. Sustainable recovery framework for ELV industry Malaysia

lighted some deficiencies, particularly in the areas of skilled labor and the importance of a design strategy. Addressing these gaps and effectively integrating these components will significantly boost sustainability in Malaysia's auto part recovery industry, thereby minimizing environmental impacts and maximizing resource utilization. The subsequent sections will further elaborate on these critical enablers.

### Strategic location

The companies are strategically located in Selangor, near Port Klang, and in Ipoh town, making it convenient for customers to access their used auto parts. These businesses primarily focus on trading reuse and recycling used auto parts rather than remanufacturing. From the interviews, the respondents mentioned that their company serves as a transit hub for importing and exporting used auto parts, mainly from Japan, to various countries in ASEAN, Europe, and the Middle East.

### Expert business owner

Most of the respondents have been involved in reusing and recycling auto parts for over a decade, indicating their extensive experience in this field. Some of these businesses inherited the trade from family members who have been in the industry for more than 30 years. They are actively engaged in associations and other groups that provide them with information and knowledge to enhance their business operations. These groups also organize meetings, discussions, and awareness campaigns to promote reuse and recycling and to encourage remanufacturing activities. Additionally, some of the business owners have attended the Repair, Reuse, Recycle, Remanufacture, Service, and Spare Parts (4R2S) course organized by government agencies to deepen their knowledge. The measure can improve their productivity and business activity.

### Efficient process

The generic remanufacturing process flow will be used to evaluate the baseline capability of the respondent company as an ELV recovery operator and their potential to facilitate the remanufacturing industry in Malaysia. The process was reviewed based on the generic ELV recovery steps obtained from the literature and compared to the MS 2697:2018 standard (Department of Standards Malaysia, 2018). Based on the respondents' explanations and on-site observations, most of the companies followed the standard steps of reuse and recycling, which include core sorting, inspection, and disassembly, without conducting the cleaning and testing steps. However, two companies performed the complete remanufacturing process, which includes core sorting, disassembly, cleaning, part replacement, repair and restoration, inspection and testing, painting, warranty, labelling, and shipping. However, this is only for specific auto parts and components based on customer requirements, terms, and conditions. In terms of process handling, it was observed that no fully automated systems were used. The companies relied on semi-automated material handling equipment, such as forklifts and trolleys, and some activities were handled entirely manually by the workers.

### Skill workers standard

The ELV recovery process relies heavily on the knowledge and skills of the workers (Loh et al., 2018). According to Matsumoto and Umeda (2011), remanufacturing practices in Japan have resulted in the development of process know-how and manpower skills. In Malaysia, the Ministry of Human Resources (2020) has published the Malaysian Standard Classification of Occupation (MASCO) 2020, which defines "skill" as the ability to carry out the tasks and duties of a given job. In this context, skill specialization is determined by the field of knowledge required, the tools and machinery used, the materials worked on or with, the technology and software used, and the kinds of goods and services produced, and not by manual labor alone (Ministry of Human Resources, 2020).

From the observations and interviews, the companies can be classified as needing skilled workers under Major Group 7: Craft and Related Trade Workers and Major Group 8: Plant and Machine Operators and Assemblers. However, most of the respondents reported facing difficulties in hiring local skilled workers due to the lack of interest among locals. The existing skilled workers, especially in the disassembly section, are foreign workers who have been trained by the business owners. The respondents suggested that the government review the minimum wage policy, which applies to both local and foreign workers, to address this problem. They hoped that the minimum wage of RM 1500 would apply to local workers only since foreign workers already receive benefits such as accommodation and transportation from the company, which local workers do not receive.

### Adequate facilities

Effective ELV management is essential to manage the continuation of the ELV generation (Othman et al., 2021). During the site visit, it was observed that the basic facilities provided by the companies were adequate, even though some of them faced challenges in allocating space for incoming cores. This only happened during abnormal events such as the last Movement Control Order (MCO) due to COVID-19. Most companies have their storage area for sorting until shipping. Each section is arranged with a designated area, such as the sorting section, disassembly section, and inspection. Furthermore, two companies have moved to new industrial areas with huge warehouses to conduct their activities conveniently. A large warehouse is advantageous for reuse and recycling activities as it allows companies to keep a significant number of incoming cores as well as auto part stocks, which can be used as a resource center for auto part remanufacturing. Other facilities like the office buildings, parking, and staff rest areas are also available. Some companies even took the initiative to sort and display their cores (used auto parts in good condition) in a showroom concept. This enables customers to easily choose and pick any auto parts that they want when visiting the premises.

### The importance of design strategy

Product design is a crucial factor in the recovery of end-of-life products. It is crucial for the ELV recovery industrial players to have a high awareness of the design strategies to be considered during product development to increase the effectiveness of ELV recovery activities. According to research by Mohamad-Ali et al. (2019), the design factors that influence the effectiveness of ELV recovery include the ability to separate parts by material, ease of dismantling components, and component lifetime.

Results from the site visit indicate that design for remanufacturing is not considered the main issue as it is not critical for their business activity, which focuses more on recycling and reuse. The respondents are more concerned about the reuse and recycling of auto parts, including the segregation of the parts to be sold as scrap. Since the respondents are vehicle recyclers, they do not have specific guidelines or requirements on remanufacturing; hence, no clear guidance exists for implementing remanufacturing. As a suggestion, to sustain Malaysia's local ELV recovery business ecosystem, there is a need for a clear guideline on specific activities such as:

1. Training and development: Continuous education to the industry players on the importance of remanufacturing activity and the impact on the environment and towards sustainability development goals.
2. Policy or guideline: The establishment of a clear guideline on the import and export of ELVs by clearly differentiating between used, reuse and remanufacturing auto parts, and metal scrap and scheduled waste. Existing standards can be enhanced by developing a specific framework for the design of the remanufacturing guidelines for both the ELV recovery industry and automotive makers.
3. Partnership: Local automotive makers and OEMs must be involved in ELV recovery activity, such as the take-back system and establishing remanufacturing policies or systems for their products and customers.

## Conclusion

This study evaluated ten selected companies on the current state of the ELV reuse, recycling, and remanufacturing industry in Malaysia, resulting in the development of a sustainable ELV recovery framework tailored to the nation's unique industry dynamics. By identifying critical enablers such as design strategies, adequate facilities, strategic locations, efficient processes, and skilled labour, the framework offers a structured and comprehensive approach to addressing the challenges of ELV recovery.

Compared to frameworks proposed in previous studies, this framework introduces a comprehensive model focusing on operational, and stakeholder-driven perspective. It addresses gaps in practical implementation, fosters greater collaboration among stakeholders, and provides a holistic strategy that integrates reuse, recycling, and remanufacturing activities. These features enhance sustainability and adaptability, making the framework well-suited to Malaysia's evolving automotive industry.

The successful implementation of this framework hinges on continued collaboration between key stakeholders, including auto part manufacturers/OEMs, ELV reuse and recycling operators, remanufacturers, and end users. Integrating existing facilities and capabilities into a remanufacturing resource center is recommended to drive industry growth. Collaborative efforts will yield several benefits, such as increasing the availability of rare parts, improving the efficiency of core sorting and disassembly, enhancing skills and knowledge within the workforce, and aligning with the Sustainable Development Goals on responsible consumption and production.

Ultimately, the proposed framework supports the goals outlined in the National Automotive Policy 2020 (NAP 2020), contributing to the vision of establishing Malaysia as an ASEAN hub for the remanufacturing industry by 2030. By addressing current challenges and leveraging collaborative opportunities, this framework lays the foundation for a sustainable and thriving ELV recovery industry in Malaysia.

### Limitation and scope of future research

While the framework offers significant advancements, its limitations must be acknowledged. This study focused exclusively on selected companies in Malaysia, which may limit the generalizability of findings to other regions. Future research should include comparative analyses with reuse, recycling, and remanufacturing industries worldwide to develop more universally applicable strategies. Addressing these limitations and broadening the scope of analysis can greatly contribute to advancing the global remanufacturing industry.

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