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Analysis of the Supply Chain Disruption Risks in the Malaysian Automotive Remanufacturing Industry- a Case Study

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Abstract: Remanufacturing has now become one of the effective strategies for reducing the negative impact on the environment by prolonging the products' life cycle in the automotive sector. Still considered as a relatively new industry in Malaysia, the low remanufacturing rate coupled with the lack of standardization are thus seen as causing a high inclination of disruption occurrences in the remanufacturing operations. As such, this paper had identified and investigated the existing disruptions in four problematic areas, namely the production planning, infrastructure facilities, distribution networking and inventory management of the automotive remanufacturing firms in Malaysia. From the SPSS analysis and calculation of the mean and standard deviation values on the semi-structured interviews that were conducted in three remanufacturing companies, the highest contributor to the disruption risks was found to have resulted from the difficulty in obtaining the spare parts components in the production planning process. By also exploring the awareness level on environmental sustainability and the significance of remanufacturing processes among the remanufacturer companies, this analysis is thus deemed useful for not only identifying suitable actions that can be taken for mitigating the various risks faced by the automotive remanufacturers in Malaysia, but also in solving the disruptions of the remanufacturing supply chain system.

Keywords: remanufacturing, uncertainties, semi-structured, case study, Malaysia

1. Introduction

The recent years had seen a growing concern on the environmental condition and increasing recognition of sustainable manufacturing industries, particularly with the enforcement of the strict environmental legislation that was introduced in Europe, Asia and North America. As a result, many corporations had taken measures to proactively employ the return back product strategy or also known as remanufacturing that not only contributes to a reduced raw materials usage and lower energy consumption, but also the decrease of waste material being sent to the landfills and ultimately, lower carbon dioxide emissions and greenhouse gas [1], [2].

Remanufacturing is defined as the rebuilding of a product that is according to the specifications of the original manufactured product by using a combination of reused, repaired and new parts, where a remanufactured product should

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at least matches the same performance as the new machines [3], [4]. According to Shabanpour et al. [5], the remanufacturing process chain begins with disassembly, which is then followed by the cleaning and inspection processes and ends with the reconditioning and reassembly stages that restore the functionality of the products. Remanufacturing is not only found to bring benefit to the environment, but also for the customer and the company's overall business.

According to a research that was conducted on the 11 selected remanufacturing companies in the UK, Ijomah et al. [3] had discovered that the correct usage of remanufacturing concept could help boost the company's profit and consequently result in higher stability of the company. This had also prompted Saavedra et al. [6] to explore the other alternatives for expanding the remanufacturing business in Brazil as well as the study on India's slow growth in the remanufacturing business activities of the automotive industries [7].

Strategic decision making has been found to be the main component of the remanufacturing system for minimizing the losses and improving the effectiveness of the remanufacturing systems. According to Subramoniam et al. [8], the gap from the limited review of the strategic decision making theory could be filled by analyzing the similar case studies that had been published under the automotive sector, such as the managerial insights offered by the Original Equipment Service (OES), Original Equipment (OE) Sales and Independent Aftermarket (IAM) automotive companies. In one of their research, Kurilova-Palisaitiene et al. [9] had considered the information flow and the possibilities of remanufactured materials as the primary reasons for the development of the lean-inspired solution of a German engine remanufacturer, while Ismail et al. [10] had explored the selection of appropriate decision making as affecting the production systems and product design performances of a remanufacturing system. Likewise, Chaowanapong et al. [11] had also conducted a survey on three Thai industries as a way of gauging the factors for influencing a manufacturing firm's decision as well as a study on the uncertain task times in the disassembly line of the remanufacturing system that was conducted by Shabanpour et al. [5]. As shown above, the implementation of a strategic decision making can thus be said as having the potential for increasing the company's profit as well as the efficiency level of the disassembly lines in the remanufacturing process.

Remanufacturing is regarded as one of the effective strategies for reducing the negative impact on the environment. In the automotive sector for example, the end-of-life vehicle (ELV) recovery stage can be considered as one of the ways for reducing the waste materials by reusing, remanufacturing and recycling the vehicle components as shown by Özceylan et al. [12], where they had conducted an investigation on the demand rates, environmental issues and capacities for influencing the network of the end-of-life vehicles (ELVs) automotive manufactures in Turkey and those of Hu et al. [13], who had investigated the ELV's cost-benefit and social values of China's automotive industries under three different treatment and process stages. From a survey that was conducted on 28 ELV stakeholders by Zhang et al. [14], four dismantling processes were also identified and ranked according to the dismantling mode prioritization that was based on the environmental sustainability constraint.

In another study however, Amelia et al. [15] had discovered one of the three manufacturers in Malaysia as opposing to the application of remanufacturing concept in the production process, where they had argued the reuse of components as not only leading to additional processes and the increase of labour costs in the disassembly process but also in compromising the final quality of the product. Similarly, the authors had also stated the local OEMs as being influenced by the three main factors constraining the remanufacturing activities, namely the customers' perception on reused products, technological deficiencies and the lack of knowledge and research in the development of the reuse programme. The slow remanufacturing rate in Malaysia as observed by Zailani et al. [16], was discovered to have been contributed by the lack of resources in funding the product return as well as the high finances and time required for measuring the return rate. As a result, its slow adoption in Malaysia's remanufacturing sector is thus seen as creating a low impact on environmental sustainability. As time progresses however, the ELV was found to have experienced a renewed interest among the remanufacturers in Malaysia, which had prompted Mohamad-Ali et al. [17] to conduct a survey on the factors (manufacturing process, EOL value, pre-production, policies, personnel and environment) for influencing the effectiveness of the end-of-life vehicle (ELV) recovery process among the aftermarket chain stakeholders.

Therefore, this paper had aimed to analyse the disruption and uncertainties faced by the remanufacturers of the automotive industries in Malaysia through the use of interviews that had been conducted on three remanufacturing companies. This paper begins by firstly describing the background of these companies, which had been selected based on their critical performances and the remanufacturing process flow in Section 2 and Section 3, respectively. This is then followed by an explanation on the data collection and methodologies used in Section 4, the findings and the effect of the remanufacturing system in the Sections 5 and 6 before concluding with the summary and consideration for future research in Section 7.

2. Methodology

As stated previously, the primary objective of this study is to evaluate the types of disruption and uncertainties that had influenced the growth of the remanufacturing sector in the automotive industries. As such, a case study was thus established to gauge the current remanufacturing condition of the automotive production industries in Malaysia through the use of semi-structured interviews that an in-depth on three selected remanufacturing automotive companies.

The semi-structured interview, which had comprised answering interview questions and performing site visits, was completed within a span of two hours. To obtain an expert's view on the current situation of the remanufacturing process, the interview questions, which had been designed according to the questionnaire format for easier and more efficient data analysis, were distributed to the respondents that had consisted of engineers, business development department managers and head of operations of the remanufacturing sectors. As shown in Table 1, the questions had composed of four different parts with Parts 3 and 4 of the questionnaire requiring the participants to specify their responses according to a 5-point Likert scale that was denoted by 1= Strongly disagree (1.00-1.79), 2= Disagree (1.80-2.59), 3= Neutral (2.60-3.39), 4= Agree (3.40-4.19) and 5= Strongly Agree (4.20-5.00) [18]. As for the site visits, this had entailed a demonstration of the remanufactured product process by the personnel of the respective companies. The statistical measurements, such as the mean and standard deviation (S.D) were subsequently calculated and analysed from the data that was obtained from the interview questions through the use of the SPSS statistical programme.

Table 1 - Details of the interviewed questions

Part	Section	Description
1	Participant data	General information such as gender, age, firm name, designation, and working experiences of the participant
2	Remanufacturing of Company	Occurrence and frequencies of remanufacturing disruptions
3	Factors that Influence Remanufacturing Sector	Factors influencing the remanufacturing sector such as product planning, infrastructure facilities, distribution networking and inventory management.
4	The remanufacturing effect	The positive and negative impact of remanufacturing on the environment, product durability and customer demands
5	Subjective question	Additional opinion-based question on remanufacturing as a whole

2.1 Company Background

There were three manufacturers selected to represent the remanufacturing automotive manufacturers in Malaysia. While Company A is known as the largest automotive distributor and importer of auto parts in Malaysia with more than 10 production lines and total revenue of between US$10 Million to US$50 Million, Company B on the other hand, is considered to be one of the top distributors and services in the automotive industries. Although Company C is of a smaller automotive remanufacturing firm, it was chosen because of its expertise in the engine remanufacturing field. It is also important to note that this form of selection, where it had involved a large market share company and a small private company had also served another purpose for reducing biases within the remanufacturing industry. The detail differences between these three companies in terms of their products, services, warranty of products, customers and price are depicted in Table 2.

Although Company A was established in 1991 and had specialized in the new and used European and Asian car auto parts, it was found to have the expertise for handling the remanufacturing and reconditioning of auto transmissions for all vehicle types. Besides being proficient in the auto transmissions remanufacturing process, this company also remanufactures other products, such as turbocharger, gearbox and clutch plate. The company also maintains its excellent performance by not only providing their customers with remanufactured products that are at par with European's quality but also offer an end to end solution for vehicle maintenance that includes consultation and part installation. A three months warranty period is also provided for every product that is remanufactured according to the OEM standards. This company had consisted of walk-in customers and local collectors but was revealed to have a preference for collecting the used items from the latter with the spare parts sourced from the local suppliers. While this company had stated the price of remanufactured items to be 65% lower than those of newly manufactured products, the end figure would still depend on the exchanged parts costs of the remanufacturing process.

Company B is well-known for providing excellent products with technical back up and services that adhere to a strict quality control standard, where it ensures each of its purchased parts had complied with the manufacturer's safety specifications. As shown in Table 2, since Company B remanufactures turbochargers, fuel systems, air systems, starters, alternators and speedometers, its customer base is found to have been mainly consisted of walk-in customers, but with a higher percentage of their smaller branches, which had acted as their collectors. The product warranties of the remanufactured products were fixed at three and six months, respectively for parts repair and new parts exchanges, while the price of the whole remanufactured product was fixed at half of the newly manufactured product. Besides getting the spare parts from the local suppliers for repair and exchange purposes, this company also produces some the car components for its remanufactured product.

Although Company C is a small private remanufacturing company that processes the engine blocks of the heavy vehicles, its remanufacturing process flow is almost the same as other remanufacturing companies. Apart from providing its remanufactured product with a three months warranty period, this company was also found to only liaise with walkin customers with its spare parts obtained from a local supplier. The price of its products was found to have depended on the types of exchanged or repaired parts as well as those of service charges.

Despite exhibiting different types of policies, warranty periods, price and types of remanufactured products, these three companies had shared a common trait by providing their customers with the best quality products and customer service.

Table 2 - A detailed summary of the selected companies

Company	Remanufactured Parts	Customer	Supplier of Components	Warranty (months)	Price
A	Turbochargers, clutch plate	Local collectors and walk-in	Local suppliers	3	65% of newly manufactured product
B	Turbochargers, fuel system brake system, starter, alternator, speedometers	Small branch act as a collector Walk-In	Local supplier Self production of components	6	Half of the newly manufactured product
C	Engine, air valve	Walk-in	Local supplier	3	Depends on the exchange and repair parts

2.2 Remanufacturing Process Flow

Company A, Company B and Company C had demonstrated almost the same remanufacturing process flow as exhibited in Figure 1, where the straight line represents the forward path from the customer to the company, while the dashed line signifies the reverse flow from the remanufacturing company to their customers. As shown in Figure 1, the forward flow had consisted of the first path from the collector to the remanufacturer, while the second path denotes those from a walk-in customer to the remanufacturer. While the customers for Company A and Company B are mostly represented by the first path, those from Company C however, was found to have consisted mainly of walk-in customers. The remanufacturing process flow of all three companies as depicted in Figure 1 can thus be described as consisting of the de-assembling or inspection, parts cleaning, repair or exchange, reassemble and testing processes.

In the first step, the used items will initially be inspected and de-assembled by a highly skilled technician to identify the cause of the problem before proceeding to the cleaning process. At this point, each of the de-assembled parts undergoes a deep cleaning process, which includes sandblasting and a high-pressure degreasing wash to achieve the desired standard surface. The subsequent repairing and part changing stage then entail reconditioning the parts by either repairing or exchanging the faulty pieces with newly manufactured components, which could be obtained from the company’s parts production inventory (as seen in Company B) or their respective suppliers. Finally, the reassembled parts are subjected to a quality and performance testing to ensure its compliance with the OEM standard and specification before they are returned to the customer. The quality and performance of remanufactured item were tested by machine test regarding their functionality, for example, speed sensor, brake test, turbo test and electronic control unit (ECU) test.

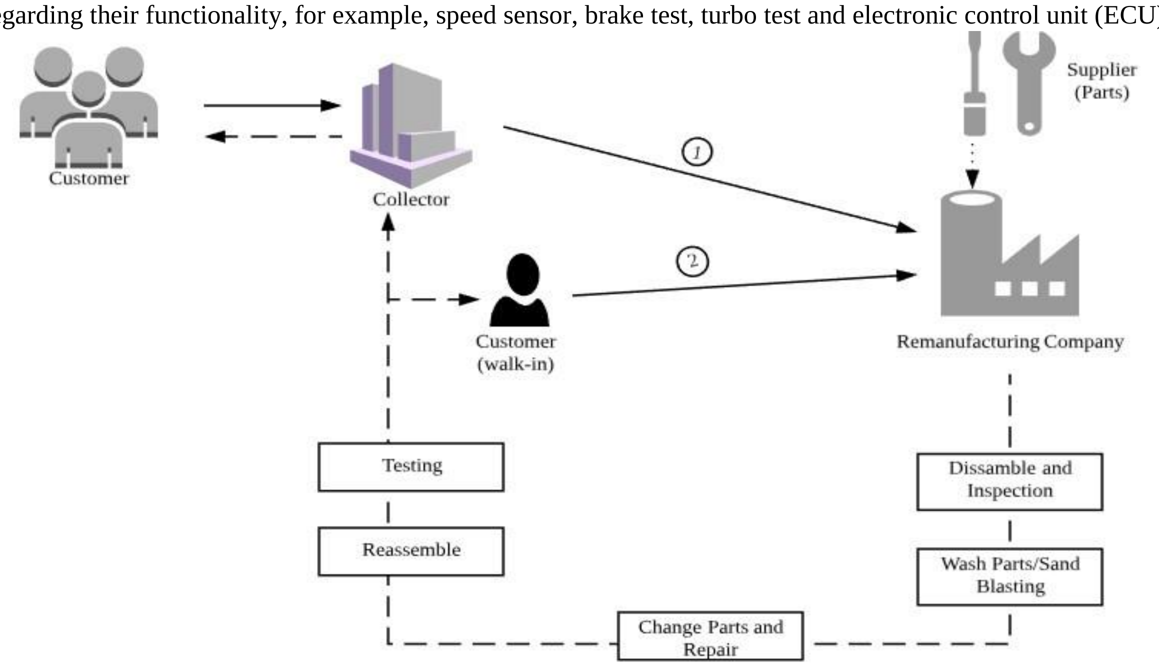

Fig. 1 - Remanufacturing process of the selected companies

3. Results and Discussion

The data from the semi-structured interviews that were conducted on the three companies were then used to identify the disruption factors from the production planning, infrastructure facilities, distribution networking and inventories management [19] and remanufacturing effects to the environmental and economic system.

Disruptions in production planning are generally associated with the interruptions such as machine breakdown, lack of professional workers, failure to get reused item, mismatch of process timing occurring during the production process that may have an impact on its rate of production and product quality [20], [21]. For this reason, while disruptions on a carefully planned production flow can be regarded as impairing a company's performance, the outcome of a company's rate of production, on the other hand, can thus be seen as being influenced by those affecting its infrastructure facilities. As for the disruption factors concerning distribution networking, these are related to the delivery routes and carbon emissions that were used for fulfilling the customer's demand, where the respondent was asked if the companies had considered alternative ways for reducing carbon emission. Since inventory management is seen as crucial for ensuring a smooth production system, any disruptions that occur in the inventory systems such as the lack of storage and nonstrategic inventory management are thus regarded as the cause of production delays.

The analysis of the interview questions such as the mean and standard deviation are recorded in Table 3. While the mean specifies the central value of the discrete data, standard deviation (S.D) on the other hand, indicates how close the data set values are to the mean value, where a high standard deviation denotes the data points as being distributed over a wider range of values [22]. As shown from the table, production planning was found to have recorded the highest mean, which is followed by infrastructure facilities, inventory management and distribution networking. The high mean value thus implies that most of the companies had encountered the problem associated with the same factor, wherein this case had been the disruptions occurring during the production planning process. A full explanation of the details will be further discussed below. The highest S.D that was recorded in Table 3, had also suggested the particular company as facing a more severe inventory management disruption than the other entities.

Table 3 - Statistical data from the interviewed questions

	Production Planning	Infrastructure Facilities	Distribution Networking	Inventory Management
Mean	3.70	3.64	2.92	3.15
Std. Deviation	0.46248	0.32863	0.30332	1.05475

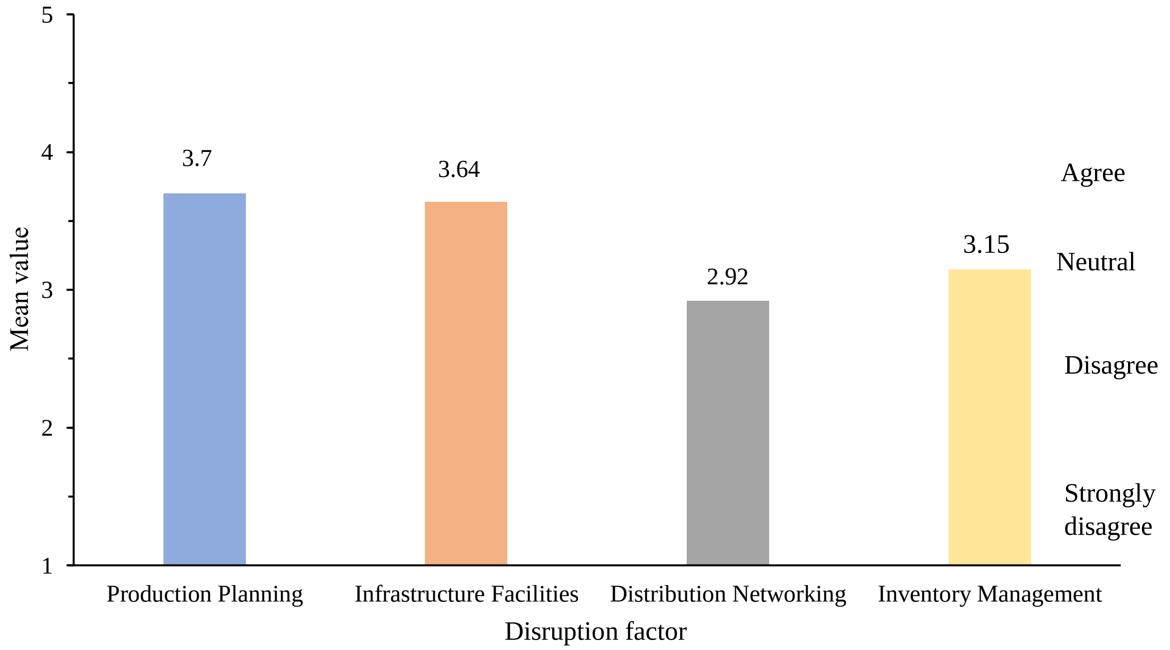

Fig 2 - Disruption factors of the remanufacturing companies

3.1 Production Planning

Production planning in the remanufacturing sector is like the operational, tactical planning and strategic design of a production system. As such, the complexities of the production planning in the remanufacturing process would very much depend on the reuse methods being employed, types of remanufactured products as well as the quality and quantity of the returned products. Since it is essential for the returned parts to undergo inspection before they can be transformed into raw materials or disassembled for reuse [19-20], the manufacturer would then be required to assimilate the production of a remanufacturing product with newly purchased parts from the suppliers and the recovered parts from the returned products [25].

For this reason, any uncertainties that disrupt the production planning process can be seen as resulting major cost, image and quality damages on the company. This situation is then addressed by including the six contributing factors in the interview questions, namely those that had affected product quality, the return rate of the reused core, process timing, remanufactured price and the availability of purchased parts from suppliers, which are shown in Table 4.

While the average mean had shown a range of between 3.6 and 4.8, S.D on the other hand, was found to have a range of between 0.4471 and 1.00. The spare parts availability was found to have recorded the highest mean value (4.8), which was followed by the rate of return core (4.0) with the other factors sharing the same mean value. Based on the interview that was conducted on the three companies, all of the respondents had agreed the difficulties in obtaining the spare parts from their suppliers as being the main problem faced by the remanufacturing sector. Once the reused core had undergone inspection and the disassembly process, the repair and replacement of the faulty parts would then require the reassembling and testing of the new parts, which in this case may be affected by the slow parts availability from the suppliers. As an example, the longer lead-time that is usually observed in the replacement of uncommon defective components is found to be caused by parts shortage, which had to be ordered from overseas or sourced from other suppliers at a higher price. Since there might be a possible cost increase of the remanufactured core, the customer is then given the option of either waiting for the arrival of the newly ordered component or bearing the higher cost.

Although a high mean value was observed in the used core's return rate, where the slow return rate is found to have a possible impact on the remanufacturing sector's growth, a standard deviation of 1.00 had, however, indicated only certain companies as facing this issue. While the product quality of the remanufactured good is not found to be an issue for all the three companies, each of these companies, however, had cited the worker's low remanufacturing skills as being a problematic issue. Since the lack of skills can be solved by sending the workers for technical training, priorities then should be given for overcoming the spare parts availability issue that is detected in the production planning process.

Table 4 - Mean and std. deviation of the production planning factors

	Product Quality	Remanufacturing Skills	The rate of Reused Core	Process Time	Price of remanufactured Product	Availability of Spare Parts
Mean	3.60	3.60	4.00	3.60	3.60	4.80
Std. Deviation	0.54772	0.54772	1.00	0.54772	0.54772	0.44721

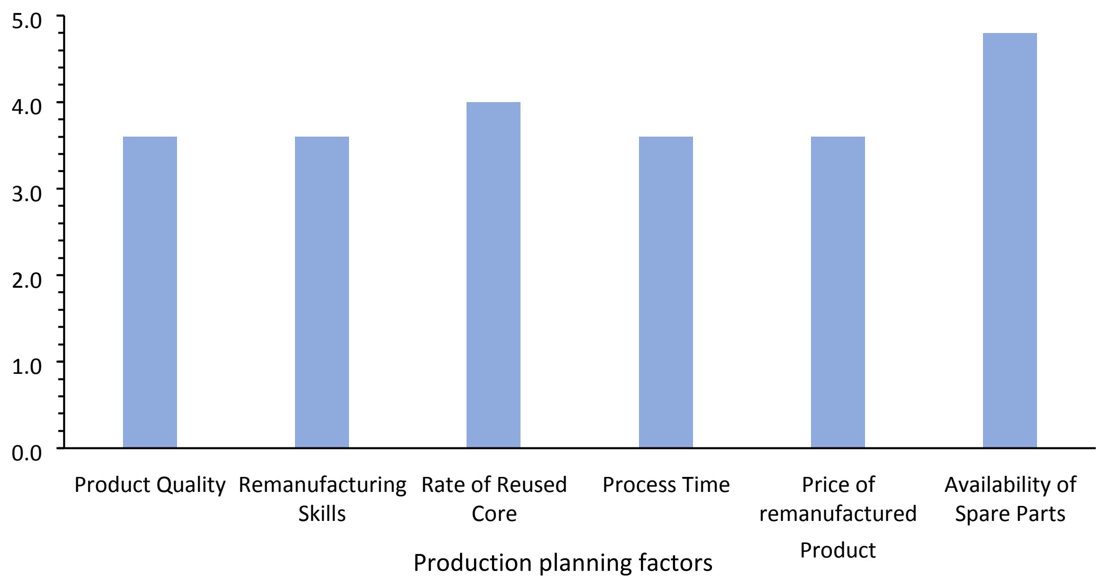

Fig 3 - Mean graph of production planning factors

3.2 Infrastructure Facilities

This section analyses the main factors for causing the uncertainties in the infrastructure facilities since they had been proven to be the second highest risk factor affecting the remanufacturing sectors. With the main infrastructure facilities being recovery and collection facilities of the remanufacturing industry, any disruptions on these facilities would then be seen as affecting the costs, demand (e.g., quantity) and availability of the returned product [26]. As the facilities limitation was found to have exhibited the highest mean value, this implies that there had been a low utilization of the remanufacturing facilities in the remanufacturing sector.

The collection rate was also found to have contributed to the facilities disruption since the remanufacturer would be required to utilize the used core in its remanufacturing process. While the collection rates for Company A and Company B had depended on their branches or independent collectors to gather the used core, this factor, however, is considered to be important for Company C as it had only relied on their walk-in customers. The lack of facilities should also spur the government to consider setting up more facilities as a way of encouraging firms to utilize the remanufacturing concept in their systems. Besides that, skilled workers is important in the management of CLSC. Workers need to be exposed to a good psychosocial culture so that a healthy workplace environment can be created, subsequently encouraging workers to excel in their assessment [27]. Apart from being deprived of skilled workers, the slow return rate in the remanufacturing process of these companies was also found to be caused by the issues resulting from the collection centres. As such, it is important that these facilities disruptions are fully addressed prior to implementing the first phase of the remanufacturing process so that further consequences on the whole remanufacturing system can be avoided.

Table 5 - Mean and std. deviation of the infrastructure facilities factors

	Facilities Limitations	Collection Centre Limitation	Lack of Workers	Collection Rate	Government Roles
Mean	3.8000	3.400	3.6000	3.8000	3.6000
Std. Deviation	0.44721	0.5477	0.54772	0.83666	0.54772

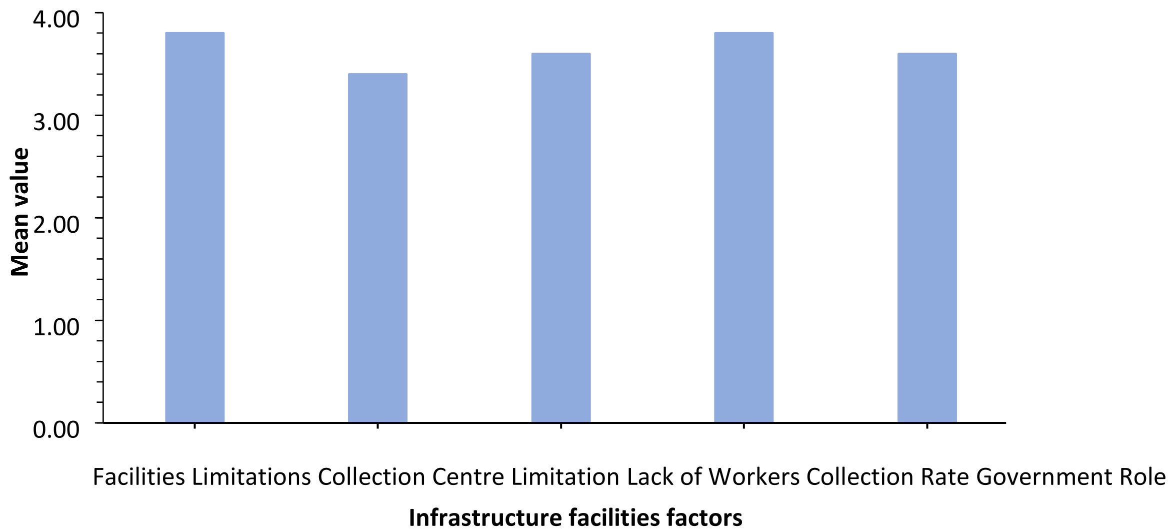

Fig. 4 - Mean graph of the infrastructure facilities

3.3 Inventory Management

This section provides an analysis of the inventory management in terms of the complexities faced during the uncertain product returns as well as the coordination of its remanufacturing production [28]. As this factor was categorized as neutral in Table 3, this meant that the inventory management factor had neither contributed to nor disrupted the remanufacturing processes in Malaysia. Despite having their own inventory management systems, these companies were found to have exhibited a low rate of inventory issue in their remanufactured products.

There had also been fewer occurrences of customer demand uncertainties since these remanufacturers were found to have discussed the replacement/repaired and cost issues of the used core with their customers prior to undertaking the next stage of the remanufacturing process. While the production flow of the remanufacturing product was revealed to have not affected the inventory management, the remanufacturing rate, however, was discovered to be affected by the output flow of the scheduled production. A mismatch in the production schedule may occur because of either internal factor such as those affecting within the manufacturing system and its facilities or the external factors caused by their retailers, suppliers, and customers. As such, the neutral inventory management factor as shown in Table 6 had thus implied the firms as being capable of resolving the issues associated with their respective inventory management systems.

Table 6 - Mean and std. deviation values of the inventory management factors

	Lot-sizing	Customer Demand	Production Mismatch Schedule
Mean	3.4	3.0	3.0
Std. Deviation	0.50990	0.63246	0.44721

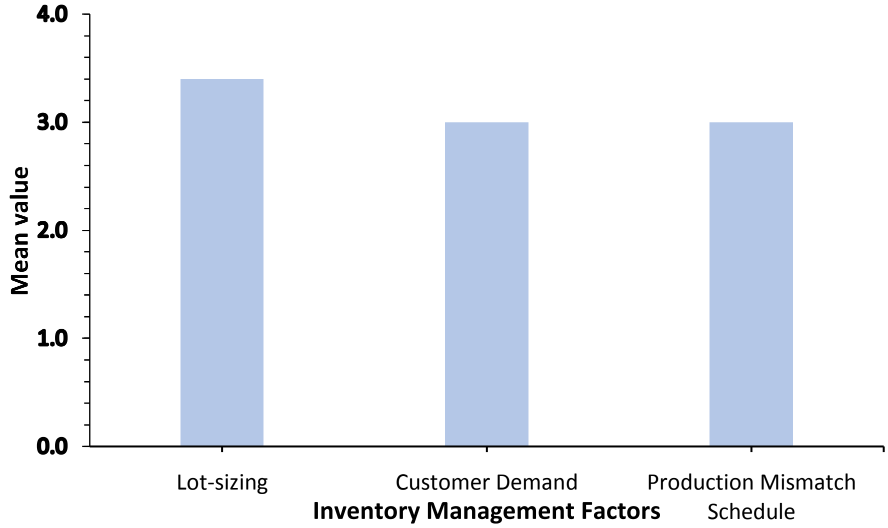

Fig. 5 - Mean graph of the inventory management factors

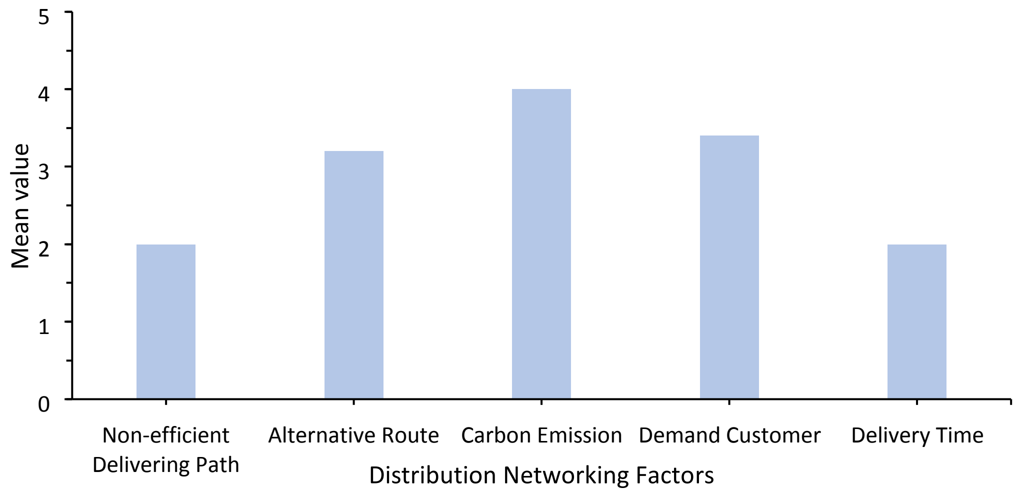

Fig. 6 - Mean graph of the distribution networking factors

3.4 Distribution Networking

This factor was found to have the least disruption on the remanufacturing sector since all of these three companies were found to have exhibited an efficient delivery system in terms of cost savings (e.g., vehicle petrol, toll) and delivery time (e.g., shortest route). Despite facing certain issues such as the late delivery times because of the obstructions occurring along the delivery path, these remanufacturers had still placed high importance on carbon emission and its impact on the environment as well as its delivery efficiencies by ensuring the regular maintenance of their vehicles.

Table 7 - Mean and std. deviation values of the distribution networking factors

	Non-efficient Delivering Path	No alternative Route	Carbon Emission	Demand Customer	Delivery Time
Mean	2.00	3.20	4.00	3.40	2.00
Std. Deviation	0	0.58310	0.31623	0.24495	0.31623

3.5 Remanufacturing Effect

The opinions on the remanufacturing impact as provided by the remanufacturers are thus discussed in this section. As depicted in Table 8, most of the respondents from these companies were found to have a serious concern about the remanufacturing effects on the environment. In this case, the remanufacturers are not only required to satisfy their customers' needs but also to adhere to the sustainable development concepts such as lesser consumption of raw materials and energy savings. Since all of the respondents had shared the common opinion of the remanufacturing process leading to the reduction of waste materials being sent to the landfills, this process can thus be regarded as one of measures for not only overcoming the landfill issues, but also in reducing the consumption of raw materials through its reusable parts [8], [29], [30], [31].

Although the reuse and recycling concepts that were included in the remanufacturing process were found to have prolonged the shelf life of used and worn-out products, it is still important for the automotive remanufacturers to identify the products that are suited to be remanufactured and with a reasonable cost that does not exceed the price of newly manufactured products. With a reasonably shorter life cycle, the firms may consider increasing the cost of these remanufactured products as long as there are no additional complexities incurred in the remanufacturing process. For this reason, a typical remanufactured automotive product is not only used for fulfilling the customers' needs but can also be used for reducing the cost of new production [30].

These companies were therefore found to have a high level of awareness on the importance of reducing landfill disposals as a way of maintaining environmental sustainability, which were shown by the use of the remanufacturing process for prolonging the product's life cycle as well as its potential for providing benefits in terms of raw material usage, customer satisfaction and company profit.

Table 8 - Mean and std. Deviation values of the remanufacturing effects

	Company Loss	**Sustainable Environment**	**Landfills**	**Raw Materials**	**Life Cycles**	**Customer Demand**
Mean	4.00	4.00	4.40	3.80	3.80	4.00
Std. Deviation	0	0	0.245	0.20	0.20	0

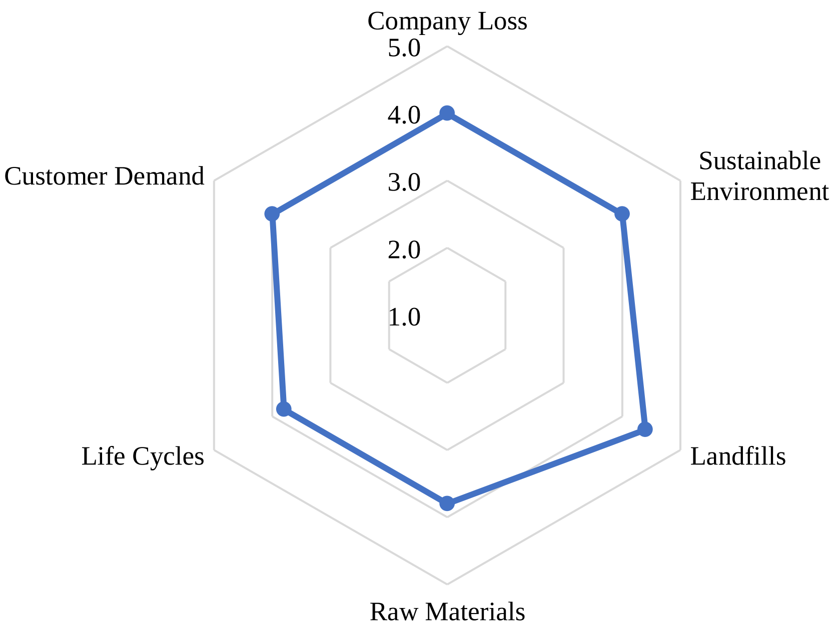

Fig. 7 – Mean value of rremanufacturing effects graph

4. Conclusion

This paper aims to identify the current situation of the remanufacturing sector as well as to investigate and analyse the main disruption factors that had contributed to the slow growth of the remanufacturing industries in Malaysia. Through the use of semi-structured interviews, the disrupting factors had been identified and classified into the four major categories of production planning, infrastructure facilities, distribution networking and inventories management that had affected the remanufacturing industries. From the comparison of the mean and standard deviation values, the highest disruption factor was found to have been resulted from the difficulties in getting the spare parts during the production planning process, which were followed by facilities infrastructures, inventory management and distribution networking. The remanufacturing effect in terms of the awareness level among the manufacturers was also analysed, where they were found to have placed a higher priority on environmental sustainability as opposed to profit-making.

The disruption in obtaining the spare part of a particular component can then be solved by creating an inventory of uncommon spare parts that had required a longer order lead-time. For this reason, the remanufacturers are advised to identify these rare components from their respective suppliers and to order them in advance. Although this method may result in an increase of the remanufacturing cost, it would nevertheless help to shorten the remanufacturing process, not to mention providing customer satisfaction and elevating the company's reputation level. Lastly, the disruption analysis can be widened by not only investigating the government's role in Malaysia's remanufacturing sector, but also the detailed life cycle, functionality and process complexities of the remanufactured parts. As Malaysia is active in implementing the Fourth Industrial Revolution (IR 4.0) in the automotive sector, remanufacturing will be considered as important as one of the recovery methods such as recycling, refurbished and repaired. In addition, awareness of the benefits of remanufactured goods should be exposed to consumers so that they are aware that remanufacturing not only save the environment but also save costs and energy which can lead to green and more economical life.

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References

[1] Yang, S. S., H. Y. Ngiam, S. K. Ong, and A. Y. C. Nee. (2015). The impact of automotive product remanufacturing on environmental performance *Procedia CIRP*, 29, 774–779.

[2] Firdaus, A., T. H. Setiawan, and J. I. Reynaldy. (2018). Barriers to the implementation of green construction : a case study in Bandung, Indonesia *The International Journal of Integrated Engineering*, 10, 1–7.

[3] Ijomah, W. L., C. McMahon, and S. Childe. (2010). Remanufacturing - a key strategy for sustainable development *Design and Manufacture for Sustainable Development 2004*, 51–63.

[4] Mok, H. S., H. S. Song, D. J. Kim, J. E. Hong, S. M. Lee, and J. T. Ahn. (2015). Determination of Failure Cause in Remanufacturing *Procedia Engineering*, 100, 14–23.

[5] Shabanpour, N. and M. Colledani. (2018). Integrated Workstation Design and Buffer Allocation in Disassembly Systems for Remanufacturing *Procedia CIRP*, 69, 921–926.

[6] Saavedra, Y. M. B., A. P. B. Barquet, H. Rozenfeld, F. A. Forcellini, and A. R. Ometto. (2013). Remanufacturing in Brazil: Case studies on the automotive sector *Journal of Cleaner Production*, 53, 267–276.

[7] Sinha, A., S. Mondal, T. Boone, and R. Ganeshan. (2017). Analysis of issues controlling the feasibility of automobile remanufacturing business in India *International Journal of Services and Operations Management*, 26, 459.

[8] Subramoniam, R., D. Huisingh, and R. B. Chinnam. (2009). Remanufacturing for the automotive aftermarketstrategic factors: literature review and future research needs *Journal of Cleaner Production*, 17, 1163–1174.

[9] Kurilova-Palisaitiene, J. and E. Sundin. (2015). Toward pull remanufacturing: A case study on material and information flow uncertainties at a German engine remanufacturer *Procedia CIRP*, 26, 270–275.

[10] Ismail, H. N., P. Zwolinski, G. Mandil, and D. Brissaud. (2017). Decision Making System for Designing Products and Production Systems for Remanufacturing Activities *Procedia CIRP*, 61, 212–217.

[11] Chaowanapong, J., J. Jongwanich, and W. Ijomah. (2018). The determinants of remanufacturing practices in developing countries: Evidence from Thai industries *Journal of Cleaner Production*, 170, 369–378.

[12] Özceylan, E., N. Demirel, C. Çetinkaya, and E. Demirel. (2017). A closed-loop supply chain network design for automotive industry in Turkey *Computers and Industrial Engineering*, 113, 727–745.

[13] Hu, S. and Z. Wen. (2017). Monetary evaluation of end-of-life vehicle treatment from a social perspective for different scenarios in China *Journal of Cleaner Production*, 159, 257–270.

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

[15] Amelia, L., D. A. Wahab, C. H. Che Haron, N. Muhamad, and C. H. Azhari. (2009). Initiating automotive component reuse in Malaysia *Journal of Cleaner Production*, 17, 1572–1579.

[16] Zailani, S., K. Govindan, M. R. Shaharudin, and E. E. L. Kuan. (2017). Barriers to product return management in automotive manufacturing firms in Malaysia *Journal of Cleaner Production*, 141, 22–40.

[17] Mohamad-Ali, N., R. A. Raja Ghazilla, S. H. Abdul-Rashid, and A. Ahmad-Yazid. (2019). Aftermarket survey on end-of-life vehicle recovery in Malaysia: Key findings *Journal of Cleaner Production*, 211, 468–480.

[18] Sekaran, U., & Bougie, R. *Research Methods for Business: A Skill-building Approach*. 2003.

[19] Govindan, K., H. Soleimani, and D. Kannan. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future *European Journal of Operational Research*, 240, 603–626.

[20] Hatefi, S. M., S. M. Moshashaee, and I. Mahdavi. (2019). A bi-objective programming model for reliable supply chain network design under facility disruption *The International Journal of Integrated Engineering*, 6, 80–92.

[21] Hishamuddin, H., R. A. Sarker, and D. Essam. A disruption recovery model for a single stage production-inventory system.

[22] Livingston, E. H. (2004). The mean and standard deviation: What does it all mean? *Journal of Surgical Research*, 119, 117–123.
[23] Kenné, J. P., P. Dejax, and A. Gharbi. (2012). Production planning of a hybrid manufacturingremanufacturing system under uncertainty within a closed-loop supply chain *International Journal of Production Economics*, 135, 81–93.
[24] Jindal, A. and K. S. Sangwan. (2014). Closed loop supply chain network design and optimisation using fuzzy mixed integer linear programming model *International Journal of Production Research*, 52, 4156–4173.
[25] Shi, J., G. Zhang, and J. Sha. (2011). Optimal production planning for a multi-product closed loop system with uncertain demand and return *Computers and Operations Research*, 38, 641–650.
[26] Current, J., S. Ratick, and C. ReVelle. (1998). Dynamic facility location when the total number of facilities is uncertain: A decision analysis approach *European Journal of Operational Research*, 110, 597–609.
[27] Chan, S. W., A. H. N. Aziati, R. Z. Rasi, F. B. Ismail, R. Ruslan, R. Ramlan, N. Syereena, M. F. Ahmad, S. S. Omar, I. Zaman, and F. Anuar. (2018). Psychosocial workplace hazards and workers' health in factory sector *The International Journal of Integrated Engineering*, 10, 136–141.
[28] Inderfurth, K. and E. Van Der Laan. (2001). Leadtime effects and policy improvement for stochastic inventory control with remanufacturing *International Journal of Production Economics*, 71, 381–390.
[29] Tosarkani, B. M. and S. H. Amin. (2018). A possibilistic solution to configure a battery closed-loop supply chain: Multi-objective approach *Expert Systems with Applications*, 92, 12–26.
[30] Barker, S. and A. King. (2007). Organizing reuse: managing the process of design for remanufacture (DFR) *the Proceedings of POMS 18th Annual Conference*,.
[31] Kusrini, E. and A. N. Parmasari. (2020). Productivity improvement for unit terminal container using lean supply chain management and single minute exchange of dies (SMED): A case study at Semarang Port in Indonesia *The International Journal of Integrated Engineering*, 1, 122–131.