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LOCOMOTIVE REMANUFACTURING TO SUPPORT SUSTAINABLE DEVELOPMENT: LESSONS LEARNED FROM INDONESIA

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ABSTRACT This paper analyses the contribution made by the locomotive remanufacturing to supporting sustainable development. A case study approach is used to analyse the practice of remanufacturing in the centre of locomotive maintenance, repair and overhaul situated in Yogyakarta, Indonesia. The practice of locomotive remanufacturing contributes to economic development in at least three ways: economically, socially and ecologically. The challenges of locomotive remanufacturing are also presented. This paper offers originality and contributes to knowledge in the sense that it is the first time that locomotive remanufacturing has been analysed from a macro perspective. Future research recommendations are presented at the end of the paper.
KEYWORDS: remanufacturing industry, sustainable development, transportation, ecological factors, locomotive, recycling

1. INTRODUCTION

The topic of remanufacturing falls under the broader theme of sustainable manufacturing, which has received considerable scholarly attention in recent years. This is partly due to a growing trend amongst government bodies, such as European Union Directives, Waste Electrical and Electronic Equipment (WEEE), the Kyoto Protocol, and End-of-Life Vehicles (ELV) in favour of adopting more environmentally friendly manufacturing practices and regulations. Economic analysis has shown remanufacturing to be a viable prospective business model [1], and one that is environmentally friendly from an ecological perspective [2]. Remanufacturing is not only viewed as an effective way to minimise discarded waste, but also as part of a company's manufacturing and marketing strategy [3].

The concept of remanufacturing has been well documented in literature and applied in various industries across different countries ([6], [7]). China, for example, has been actively engaged in implementing sustainable manufacturing, particularly remanufacturing. To support this implementation, the country has set up a strategic plan to develop the remanufacturing industry [8]. Japan ([9], [10]), India ([11]–[13]) and Australia [14] have all adopted similar practices.

In terms of product types, automotive products are the most commonly remanufactured [3], but other product types such as photocopiers [7], [12], [15], forklift trucks [16], toner cartridges [16] and telecommunication devices ([11], [17]) are all gaining in popularity. This indicates that remanufacturing has spread widely across many different countries and product types.

Despite the popularity of remanufacturing across different industries and countries, there is still a lack of knowledge in the area for a number of reasons. First, the application of remanufacturing is still not well understood in developing countries. This is due to the fact that most studies thus far have been undertaken in developed countries, and studies carried out in developing countries are very rare. Also, the pattern of product use in developing countries is different from that in developed nations. Thus, the findings of existing studies in developed countries may not be applicable to industry in developing nations.

This lack of understanding is heightened, as the attitudes of users in developing countries are different to those in developed countries. Users in developing countries tend to use products until the end of the product's life. On the other hand, in developed countries, products are used for a certain period of time, without waiting until the products are completely un-useable.

Second, in terms of the actual products, locomotive is one of the product categories most suitable for remanufacturing and reconditioning. Unfortunately, there is a lack of studies investigating locomotives specifically. One possible reason for this could be that size of locomotives is far too large to be investigated as a single unit of analysis. To overcome this issue, many studies analyse individual parts or components of locomotives. The present study aims to address this research gap by investigating the overall locomotive as the unit of analysis.

Research questions: How do the practices of locomotive maintenance, overhaul and operations contribute to sustainable economic development?

2. METHODS

2.1. Case study: PT. Balai Yasa

This study was undertaken at PT. Balai Yasa, situated in Yogyakarta, Indonesia. The company was selected as the subject as it is a national centre for maintenance, repair and operations of locomotives. All locomotives operated in the country are remanufactured at the company. Due to its strategic position, locomotive remanufacturing is critical not only for the company, but also for the society within which it operates.

Table 1. The schedule of locomotive maintenance, repair and operations.

No.	Type of engines	Regular maintenance	Semi-final maintenance	Final maintenance
1.	Hydraulic locomotive	500, 1,000, 4,000 and 8,000 hours	12,000 hours	24,000 hours
2.	Electrical locomotive	1, 2, 3, 6 and 12 months	325.000 km or 2 years	650.000 km or 4 years

PT. Balai Yasa was established by Nederland Indische Spoorweg Maatschapij (NIS), whose main business is to overhaul both hydraulic and electrical train locomotives. The main customer of the company is Indonesian Rail Service, which is the only operator of railway services in Indonesia. The service that the company offers to its customer is not only train locomotive overhauls, but also regular maintenance, as part of maintenance, repairs and operations (MRO). The schedule of regular services and overhaul is presented in Table 1 above.

2.2. The process of locomotive remanufacturing

Used locomotives undergo a series of steps during the remanufacturing process. Once the locomotives have arrived at the company's facility, they are tested to obtain initial data regarding their general condition. Then, they are disassembled into the frame and its components, which are distributed to different shops. In the shops, the components are examined in more detail, to determine whether they qualify for further processes. Qualifying components are repaired, checked and tested for whether they can perform at a level of at least equal to a new component. At this stage many of the components have to be replaced with new ones. Mechanical, electrical and rotating components are remanufactured using latest available technology. After all components have been tested, cleaned, and reprocessed, they are rebuilt into final products. The final products are then tested before they are dispatched to customers. The overall process takes roughly 32 days, depending on the condition and type of the locomotives.

3. FINDINGS AND ANALYSIS

As pointed out by Lund [18], remanufacturing offers benefits in three broad areas: social, economic and ecological. This study confirms that opinion, within the specific context of locomotive remanufacturing. The benefits are summarised in Table 2, and will be explained in more detail in the following paragraph.

Table 2. Summary of benefits produced by the locomotive remanufacturing in Indonesia.

Economic benefit		
1.	Labour absorption	Absorbing a large number of employees Need for low level skilled and flexible workers
2.	Lower production cost	Lower price of remanufactured products than the new products
Social Benefit		
1.	Supports low cost economic production	Lower public transportation cost Low cost of transportation leads to lower production cost
2.	Increases quality of life	Reduces traffic congestion Less pollution from private, individually owned cars
3.	Supports low cost transportation	Fosters national economic growth Supports mobility of people in the country
Ecological Benefit		
1.	Recovered energy	Saving of the energy used for making the products No need to use purely virgin materials
2.	Reduce the amount of waste going into landfill	Only certain parts are replaced with new ones
3.	Reduces the use of virgin materials	Recovery of most components from cores Minimising the use of virgin materials

3.1. Economic Benefits

The social benefit of remanufacturing is that it creates jobs for a large number of people, as it can be categorised as a labour intensive business. As many as 475 people work in the case company; they typically carry out jobs manually, with minimal assistance from technology. In addition to this, remanufacturing can keep train operation costs down. From a broader perspective, the low costs of train operators help to promote economic growth.

The use of automated equipment is less suitable for locomotive remanufacturing, and is replaced with human labour. For example, to move heavy components the company typically use several employees, who work together, rather than using robotic or automatic equipment. From the perspective of manufacturers, remanufacturing is an environmentally friendly practice, as well economically efficient. Labour expenses in the remanufacturing processes are mainly intended to preserve the economic value of cores by maintaining the original shape of the products.

Producing new locomotives is much higher cost in comparison to remanufacturing used ones. The highest proportion of the cost of locomotive remanufacturing is the expense of buying new components to replace worn out parts. In many cases, the case company decided to make new components, due to cost considerations, although this takes longer time.

Literature claims that remanufacturing costs are roughly 60% of manufacturing new products [18]. However, in this study, the figure is even more impressive; remanufacturing here is found to cost less than 40% of the cost of manufacturing new products. This is due to the fact that remanufacturing is a labour intensive industry, and labour costs in Indonesia are not high in comparison with developed countries.

Remanufacturing requires a customised approach for every single component. Each component of each locomotive could be in a different condition, requiring different processing. For this reason, a large number of employees are needed to support the process of remanufacturing locomotives. Due to the custom nature of the work needed for different components, the workers in the factory, which use cellular layout design, need to be flexible. They should be multi-skilled, so that they can be rotated easily across different jobs.

The economic benefit of locomotive remanufacturing lies in the recovered value of used locomotives. There is no doubt that the cost of buying new locomotives is much higher in comparison to that of remanufacturing used locomotives. In this case study, the economic benefit of remanufacturing can be calculated using the following equation:

Economic benefit of remanufacturing = Recovered value - The cost of recovery process

The recovered value refers to the residual value once the locomotives have been remanufactured. This can vary widely depending on various factors, such as behaviour of users, patterns of use, age of the locomotive, climate conditions, and so on. The case company attempts to maximise the recovered value, as this is where the cost saving comes from.

On the right hand side of the equation above is the cost of recovery. This consists of various components, which can be broadly divided into three main categories:

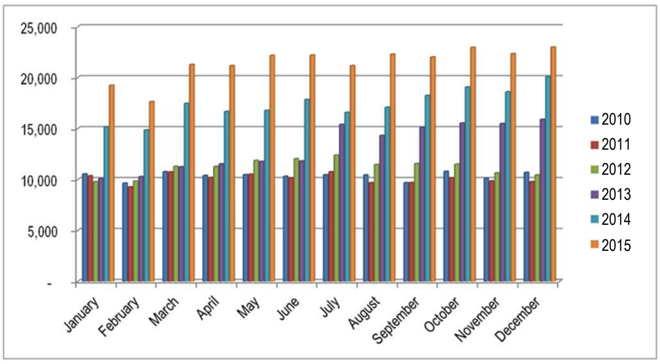
- *Labour cost.* All the jobs taking place on the shop floor are carried out manually by humans, with no automation. There is no use of robotic technology in remanufacturing processes. The use of manual labour is strongly recommended, particularly for testing and inspection processes, as these require employees to use their judgment to decide whether the components can be accepted or rejected. The cost of labour outweighs the cost of automatic technology adoption. For this reason, labour absorption is high in locomotive remanufacturing processes, which in turn promotes the welfare of the employees.
- *Cost of component replacement*. There are many components that it is not feasible to reprocess, and these must be replaced with new ones as part of the remanufacturing process. For some locomotive models, the new components are no longer available, as the models were originally produced decades ago. Sometimes the components are available, but the price of purchasing them is extremely high, and thus not feasible. To overcome this challenge, the case company decided to make these components itself.
- *Processing cost.* This includes all of the activities undertaken to restore components so that they meet specifications for ‘like new’ quality. This covers the cost of disassembling the locomotive into components, testing, cleaning and inspecting the components, as well as the use of tools and supplies.

3.2. Social Benefits

To some extent, locomotive remanufacturing affects the behaviour of people traveling to their workplace. Evidence for this is more apparent in large Indonesian cities, such as Jakarta, Surabaya and Bandung, where traffic congestion is a serious problem. Low cost of locomotive remanufacturing leads to lower operational costs for public transportation; this causes many commuters decide to use trains as their transportation method. A large number of commuters who previously drove are now using trains to get to work. This switch from use of private cars to trains has significantly reduced the amount of pollution released into the air.

Figure 1 presents the number of commuters using trains in Jakarta during the period of 2010-2015. As shown in the table, there is a growing trend of commuters using trains; this indicates that the importance of locomotive remanufacturing increases from time to time. The figure also implies that commuters can behave in a more environmentally friendly way.

From a broader perspective, customers’ decision to use trains rather than private cars offers a further economic benefit. Less cars on the road means reduced traffic congestion, meaning the government needs to spend less money subsidising oil consumption. In 2015, the government in Indonesia spent roughly 13.72 billion U.S. dollars on oil subsidies. This figure would be much higher if more commuters were using private cars.



Source: Biro Pusat Statistik [19]

Figure 1. Number of commuters using trains in Greater Jakarta

The multiplier effect of the higher rate of train usage for public transportation is that there is less pollution from private cars. The large size of the Indonesian population means there is a huge potential for producing air pollution. In fact, Indonesia has the fourth largest population in the world, and traffic congestion in several of its cities is categorised as being among the worst in the world. For example, a study revealed that Jakarta, the capital of the country, is one of the most populous urban agglomerations on earth, with a population of 10.2 million in 2014 [20]. The amount of air pollution could be huge if all commuters relied on private cars. At present, trains are the preferred mode of transportation in the capital, for a number of reasons, including reliability, affordability, and easy access to both point of departure and destination.

3.3. Ecological Benefits

There is a common belief that remanufacturing is a good way to save energy and conserve the environment. However, in practice it is not so simple. Thus, deeper analysis is required to determine whether remanufacturing is more environmentally friendly than manufacturing.

Gutowski et al. [4] have found that remanufacturing products requires less money but does not necessarily save energy. Energy saving from remanufacturing can only happen when the technology of the products is stable. When there is significant improvement in energy efficiency on new products, remanufacturing is not preferred option. This study demonstrates that locomotive remanufacturing is not only economically beneficial but also energy efficient. This is because the locomotives are made from reprocessed cores that still hold a large amount of economic value and energy. The process does not start from scratch with the production of new products from virgin materials only.

For the case company, remanufacturing is a good option to increase the life of locomotives. On average, the process can extend the life of the products by up to 20 years. In addition to remanufacturing, the case company also offers product overhauls, which can increase the life of a locomotive by in the range of 7 to 9 years.

According to interviews carried out with participants from the case company, ecological cost can be considered to be the negative impact of the remanufacturing process. The method by which to measure the net ecological benefit of remanufacturing is as follows:

Ecological benefit = (Recovered energy + avoided environmental energy) – impact of remanufacturing process

The findings of this study corroborate global empirical evidence. A study undertaken by Argonne National Laboratory demonstrated that the annual energy saving produced by remanufacturing could be as high as 400 trillion BTUs. This value is equal to 10.7 million barrels of crude oil, which would require 233 standard super tankers to transport it. Assuming an oil price of as much as USD 70 per barrel, the saving is equivalent to USD 750 million. According to the study, remanufacturing could reduce the production of carbon dioxide by 28 million tons per year. Other alternative methods to measure the environmental benefit of remanufacturing are explained in detail by Sundin [21].

From the perspective of sustainable production, product recovery activities can save a large amount of pure raw materials. A study carried out by Nasr [22] demonstrates that as much as 85% of energy used during production can be recovered via remanufacturing. The findings of the present case study confirm this opinion, although the exact figure regarding energy spending requires further more detailed analysis. Nevertheless, this figure is much higher compared to other recovery methods, for example recycling. Remanufacturing can recover both the materials of the cores, as well as the economic value from product [23] as the shape of the products is preserved [6]. The main ecological benefit of locomotive remanufacturing is that the material shape of the products is preserved; they are not burned, or melted back into their raw material, which avoids the use of virgin material.

One of the challenges of locomotive remanufacturing is that the original products are not designed or developed with product life cycle in mind. This causes difficulties for the case company during the remanufacturing process. One of the methods to cope with this issue is to use reverse engineering. However, this strategy does not always work, and it is also costly to undertake. For example, disassembling components is not always the reverse of their assembly. Some components are designed for single use only, and use permanent connectors. If a company intends to disassemble them, the components must be broken down, and the connectors are not reusable. In this case, reverse engineering is not relevant.

4. FUTURE RESEARCH DIRECTIONS

The present study directs the researcher to further investigate several research avenues. First, future research should measure the effects of an integrated sustainable supply chain on economic development. The present study only investigates the effects of a single case company on overall economic development. The results would be much more applicable if future research was to investigate the effect of integrated sustainable supply chain on overall economic development.

Another point of interest is how to assess the performance from an environmental perspective, as the reverse supply chain is intended to respond to regulation regarding this issue. Measuring supply chain performance whilst embracing various actors in the chain is a complex activity. Most existing studies examine a single company when measuring reverse supply chain performance, or analyses a reciprocal relationship between the company and its customers, the users and parties returning products [24]. The author thus considers that there is a need to develop a comprehensive performance management system integrating economic and environmental metrics, as suggested by Gobbi [25].

Another point of interest for future research directions is knowledge creation and management in remanufacturing. Locomotive remanufacturing requires skills that are specific to the job. There is no training or other formal education institutions that educate individuals on the subject of locomotive remanufacturing. Accordingly, skills and knowledge are developed in house through knowledge creation and accumulation. Reverse engineering is sometimes undertaken to develop certain areas, such as the disassembly process. However, this method is not always successful, as dismantling products is not always the exact reverse of the assembly. Another example of specific knowledge developed by the remanufacturer itself is identification of parts that typically need to be replaced if they become worn out. Workers undertaking this job should have knowledge accumulated from the past. In addition, the product knowledge possessed by the manufacturer is less relevant to remanufacturing. Thus, a potential research enquiry is: how do remanufacturing companies manage knowledge creation to support their operations?

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