

World Class Remanufacturing Productions Systems: An Analysis of Mexican Maquiladoras

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Abstract. With the vision to maintain leadership, enterprises are working to implement a green business strategy. The increase in the solid waste generation has promoted interest in the remanufacturing production system, which is considered the best end-of-life (EoL) alternative. In Mexico, remanufacturing takes place mostly in small workshops, including products as electronics, auto parts, heavy-duty engines, gas turbines, and others. However, on the Northern Border are located industrialized remanufacturer companies with global presence, these are characterized by monitoring the indicators of sustainability. This article presents an exploratory study on the current remanufacturing scenario and its main characteristics within the Mexican remanufacturing sector. This research is an analysis of three transnational remanufacturing enterprises located in this region; it selected the metalworking industrial sector. The objective of this study is to identify the elements are integrating its production system; make a comparative analysis of them and contrast them to identify similarities, differences, advantages, and disadvantages. The research is an attempt to review in a critical way remanufacturing practices and develop a theoretical framework.

Keywords: Remanufacturing enterprises · Cooperation · Case studies

1 Introduction

Remanufacturing as a highly productive industry has existed since the last century and about 40 years ago scientific research has raised considering, in the first instance, the environmental criteria and gradually considering the engineering and decision making

criteria. Remanufacturing is a production system that is increasing its acceptance in companies aware of the current environmental problems and the economic benefits it brings [1–3]. In the same way, consumers have identified the value of remanufacturing as an agent in the reduction of the environmental impact, clarifying the doubts on the purchase of a new or rebuilt product. The customer perception about the remanufactured products has become increasingly positive, not to mention the remanufacturing is demonstrably a profitable industry [4–9].

The remanufacturing is an EoL strategy characterized by offering products that comply with the same design specifications as a new one. The product is disassembled and passed through processes of cleaning, machined and inspections before they are assembled and sent to the customer, this with the aim of bringing the initial product to the original specifications of design [10]. First, this paper analyzes the context of remanufacturing productions systems, from a global perspective; then, the generalities of remanufacturing in México; and finally, the methodology, case studies and the conclusions obtained from the exploration of the collected information. Three remanufacturers companies located in Mexico participate in the investigation: two case studies include Original Equipment Manufacturers (OEM) and one Independent Remanufacturer (IR). The objective of this study is to identify the elements are integrating its production system to make a comparative analysis of them and contrast them to identify similarities, differences, advantages, and disadvantages. The research is an attempt to review in a critical way remanufacturing practices and develop a theoretical framework.

2 Understanding the Remanufacturing Production Systems

This section presents an overview on the aspects considered important in relation to Remanufacturing. A large number of publications show how remanufacturing is considered practically a panacea of Sustainable Development; since it contributes to the prevention of waste generation and uses energy already invested in the manufacture of new products as part of an ecological conscience and of social responsibility within the industrial environment. This jointly involves lucrative economic benefits due to the restoration of virtually discarded products that now satisfy with a like-new condition at a relatively low cost. However, not all products have the characteristics to participate in the remanufacturing practices and, not all companies have the necessary characteristics to be remanufacturers. In such cases, other EoL strategies and other types of business may be viable.

These operations consist of low-level activities developed according to the condition of origin of the core, there are several scenarios located in two extremes. First, a long route to the core (product recovered at the end of its useful life to be remanufactured) that is very damaged (is the worst-case scenario, because the damage on the part can be such that it is not feasible to remanufacturing, even when they have had implemented some procedures for recover it). In contrast, the core can be in excellent condition that requires very basic operations to be remanufactured (the best scenario). In addition, the type of producer can determine the process difficulty level.

The OEM offer packages of units, which include contractual liability for the maintenance of the equipment, where the remanufacturing is an internal option of cost savings, the life cycle of which overlaps with the maintenance cycle itself. The IR acquire used products that they did not design, therefore the reconstruction activities become more complex in comparison with the OEM. The IR obtain technical information by reverse engineering where a remanufacturer analyses a correctly functioning product to obtain information with which to rebuild it to the required specification on its failure [11].

2.1 Remanufacturing in the World

This section provides an overview of global trade, industries, and markets for remanufactured goods. According to United States International Trade Commission (USITC) the United States is the largest remanufacturer in the world. For the rest of the world, the countries and areas with the highest participation are: European Union according to European Remanufacturing Network (ERN), Brazil, India, China and others with less participation; all of these are described in Table 1, starting with the United States.

Table 1. Relevant aspects in countries with greater participation in remanufacturing activities

Country or area	Relevant aspects
United States	Between 2009 and 2011, the value of U.S. remanufactured production grew by 15 percent to at least \$43.0 billion, supporting 180,000 full-time U.S. jobs [12].
European Union	The value of the remanufactured products is €1.5 trillion, and it makes up an estimate 1.9% of total production value [13].
Brazil	There are over 2,000 engine remanufacturers in Brazil, 60% employ six or less workers, the remainder companies employ between 20 and 60 workers. However, several large multinational firms account for the 75% of the total value of the remanufactured auto parts [12].
India	Only the market for printed cartridges is estimated at roughly \$250 million annually. There are many restrictions for the development of remanufacturing [13].
China	The National Development and Reform Commission (NRDC) organized the first batch of automotive parts remanufacturing pilots and 42 pilot companies were involved in the remanufacturing engines. Currently, remanufacturing is an emergency industry [14].

2.2 Main Topics in Remanufacturing Operations

The industrial challenges within remanufacturing relate to three areas:

- Marketing of remanufactured products, including business models and the consideration of case studies [4, 6].
- Product design, with the aim of proposing strategies to make remanufacturing a less complex process [11].

- Remanufacturing operations or remanufacturing process technologies, it covers the development of tools, techniques and procedures leading to an improvement in efficiency in remanufacturing operations [15, 16].
- Reverse logistics and relationship with the supplier of the used product [7].

3 Remanufacturing in the Mexican Context

Mexico exported remanufactured products to the US market for \$3,059 million dollars in 2011, consolidating its position as the first supplier of that [12]. Mexico left behind two closets competitors in this type of supply in the US market: the European Union, with exports for \$820 million dollars, and China, with \$412 million dollars, as shown in Fig. 1. Almost one in three of these articles imported by the US had its service in Mexico, since the total foreign purchases of that country reaches \$10,263 million dollars in 2011. The main advantage of Mexico in comparison with other countries are the lower labor cost and the lower transportation cost owing to the country's close proximity to the US market.

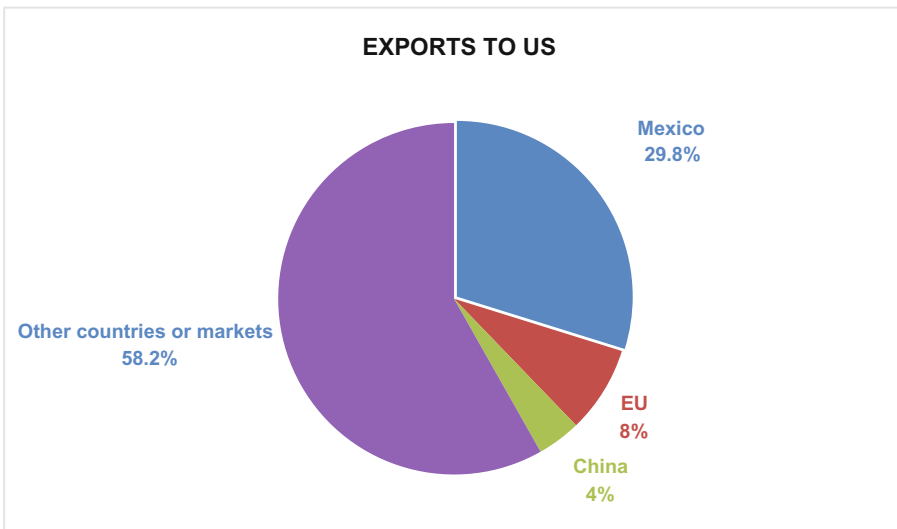


Fig. 1. Main exporters of remanufactured goods to the United States.

In information technologies goods, Mexican sales to its neighbor of the north reached \$839 million dollars, benefiting that several plants are to the south of the common border. Mexican exports of remanufactured auto parts were for \$416 million dollars. These sales led by the American companies Cardone and Remy and participated the companies Cummins, Detroit Diesel and Visteon. Mexico participates in the Free Trade Agreement (FTA) with the US; as a result, in 2011 the US exported remanufactured products to the Mexican market for \$854 million dollars, ranking third behind Canada (\$2,264 billion dollars) and the European Union (\$1,413 billion dollars). In total, exports of this type

from the US totaled \$11,735 billion dollars, a year-on-year increase of 56.4%. Mexico exports other products such as medical devices, electrical goods, air parts and heavy machinery. In Mexico, there are no specific laws to regulate remanufacturing as an industrial activity, although the country implemented since 2008 the 3R policy (reduce, reuse and recycle), giving tariff advantages to the importation of certain parts.

4 Methodology

First, a study was carried out to explain the context of remanufacturing production systems, beginning with the main participants considering a global perspective. The next phase was carrying out the case studies in three companies of the metalworking sector, as this is one of the prevailing remanufacturing sectors in Mexico. The characteristics investigated in the companies were classified according to remanufacturing operations, marketing of remanufacturing products, reverse logistics and relationship with the used product supplier according to [7].

Two OEM and one IR were selected to participate in the studies; the essential requirement was to be recognized as world-class companies, in order to identify better remanufacturing practices. Data were collected during visits and interviews with managers and remanufacturing engineers using a structured questionnaire with open-ended questions. The questionnaire proposed by [7] was useful and applied in this study. The first part of the questionnaire request general information about the company and the second part aimed to describe the remanufacturing process.

5 Case Studies

The cases of the participating companies are presented below; it is important to highlight the financial participation of transnational corporations in selected case studies. For each company, first it is defined the general characteristics and the second part of the questionnaire analyzed more specific remanufacturing aspects.

5.1 Case Study 1: Original Equipment Manufacturer

Company A is engaged in the manufacture and remanufacturing of medium-range gas turbine industrial components. Currently, it generates 1200 jobs, which mostly require technical or engineering training. The company does not offer finished products but more than 1000 different subassemblies carried out, including injectors, combustion chambers, and cases; all of which are exported directly to the US. Initially, the company's primary motivation for remanufacturing was economical; however, the company's vision currently includes a sustainable approach. This is reflected in the importance of ensuring that people's basic needs, such as shelter, clean water, sanitation, food and reliable energy, are met in a sustainable manner; as well as striving to be a company that improves the quality of the environment.

Company A being an OEM gets the core directly from the end user or from the collection centers of the same company, maintaining direct communication. When the

raw material arrives at the facilities, it is immediately classified as acceptable or not acceptable. The acceptable core goes through processes of physical and chemical cleaning, during these processes the core continues in evaluation regarding its quality and permanence in the process. The company has internal suppliers (collection centers and manufacturing area of new components) and external suppliers; these last suppliers provide parts for which a recovery process not developed or the company does not manufacture directly. The relationship with the suppliers is harmonious because the implementation of the Lean Manufacturing philosophy and the Just in Time system; based on commitment, trust and long term relationships.

The non-recoverable parts are sent to the recycling, whose destination implies the casting to be mostly metallic components. For the development of the process, the operations of core reception, inspection, disassembly, cleaning, machining, assembly and testing are performed in general manner. Each phase of the process is complex because during the development of the remanufacturing operations the worker's criterion for making decisions is needed, which must have sufficient experience and training. The company considers as its most valuable resource the employees' knowledge about the process, proposing quality assurance in products that include an extended warranty like-new products, as well as technical support and maintenance during its useful life.

5.2 Case Study 2: Original Equipment Manufacturer

Company B is an OEM remanufacturing fuel systems for diesel engines; it includes 12 families of finished product and about 2000 part numbers of finished product; remanufactured products include injectors, actuators, pumps, and modules. Currently, this business unit generates more than 1600 jobs and the products are offered through distributors. The main motivation of the company to carry out remanufacturing operations is economic, without impairing the environmental benefits associated with the business. However, the company recognizes, as a key factor to achieve greater profitability of its business, it is mandatory to promote the potential of its employees, in order to ensure their commitment and effort. Therefore, being a world-class company involves responsibility to help improve the communities in which employees work and live. It is a responsibility the company make possible through its actions and the activities of its employees.

The remanufacturing process starts with obtaining the core; first, the core is taken to authorized collection centers, so the reverse logistics is presented in the following order: end user, collection centers and remanufacturing plants. Once the core reaches the plant, the raw material goes through a classification process, this consist of the next activities:

1. Assigning a core number to each part number of finished good.
2. Once in the collection center, visual aids are used to identify the core as good or bad.
3. The core is sorted and separated according to the specified characteristics.
4. The core is send to remanufacturing plant once classified and separated by part number.

The non-recoverable core is willing to recycle and in the worst-case scrap. The acceptable core receives the operations of disassembly, pre-washing, inspection and

evaluation of components, proceeding with the process of saving parts, washing detail, functional tests and, finally the packing. In analyzing the process required for remanufacturing in Company B, it can be affirmed that the most complex process is salvage of parts. It requires the implementation of restoration and validation techniques to ensure functionality of the components, according to the specifications of design, like new products. Likewise, the assembly process requires skills and specialized equipment for its implementation.

The company has both internal and external suppliers; the company's policy is to manage suppliers as partners, resulting in a cordial and effective. Some operations of the process are subcontracted because the volume required does not justify an investment in specialized equipment. Company B offers technical support through service, quality and product engineers; the customer can contact them by telephone or online.

5.3 Case Study 3, Independent Remanufacturer

Company C is an IR remanufacturing auto parts for the automotive industry, for sale under many private label names. It is the newest and most sophisticated starters and alternators facility in the world; currently, this business unit generates more than 2,000 jobs and receives daily no less than 25,000 damaged cores, which will leave the facilities with a five-year warranty. Company C calls itself sustainable; arguing the remanufacturing process they develop contributes for the reduction of the carbon footprint and the reduction of solid waste. The company considers that its most important contributing to sustainability is properly to recover as many components as possible from the core. According to the information provided in the interview, it is concluded that the company has a string interest in environmental issues; which has verified how sustainability is really a profitable business.

Remanufactured products are marketed through retail distributors; these function at the same time as collection centers, which in the buying process offer a bonus for leaving the core. The reverse logistic presents the flow: end user to collection centers (retailers) and finally to the remanufacturing plant. The classification of the core is done in a partial way in collection centers separating by models and part numbers; more specifically in the remanufacturing plant using a support catalog. The core has a bar code indicating the origin condition, so that the sorting of products is done in a semi-automatic way. The company has internal and external suppliers, maintaining a friendly business relationship. Some activities are subcontracted due to the need for highly specialized machinery and equipment; the subcontracting strategy aims to reduce costs and ensure the quality of products.

The process of remanufacturing at Company C develops the following stages: disassembly, abrasive cleaning with sandblasting, lubricating, final assembly (reconstruction), and functional tests (validation). The assembly process and reconstruction are considered as the most complex processes because these are where the greatest number of failures are detected. Finally, non-recoverable parts are classified as scrap and the parts recovered are sold to customers with a warranty as a new product. In case of product failure there is technical support personnel who can be contacted by phone to solve any inconvenience. Workers generally perceive a

company at the forefront in proposing new processes for the recovery of a greater number of components applying advanced technology.

6 Analysis of Case Studies

The case study companies are strategically located on the Northern Border of Mexico; remanufacturing products with mainly metallic components, these characteristics assure them a success in their operations. First, its closeness to the US (which is the main destination of its products) decreases the costs for transportation of materials. In addition, recovering metallic components is economically profitable due to the constant increase in the prices of alloys coupled with their scarcity. Another important feature for the correct functioning of these companies is the availability of labor highly specialized in manufacturing processes, with technical and engineering skills available at low cost.

The analyzed companies generate more than a thousand jobs each one; produce high volumes of production, organized in small lots including a high variety of products. All three companies are self-rated as sustainable; in the case of Company C the process they develop is their main argument, while Company A is very clear about its mission at this concern and its implications. Company B is strongly moving in that direction by having social considerations and highlighting the value of its workforce, however, the possibility of increasing the level of application in sustainability tools is an opportunity area.

The sales strategy is through distributors also used as collection centers. The core is classified in the collection centers, but is evaluated again in the remanufacturing plant. Participants agree to have both, internal and external suppliers and to strengthen a good relationship with supplier. They also subcontract some operations for economic reasons and to ensure product quality, which allows them to reduce the complexity of the operations.

The companies agree about the phases of the remanufacturing process: initial inspection, cleaning, disassembly of components, assembly that includes machining operations, functional tests and final inspection. The informants ensure that the process of recovery of components (in the assembly phase) is the most difficult because it requires the experience and training of employees to make decisions; the informants commented that the processes require specialized technical skills and the learning curve in the remanufacturing process is much slower compared to conventional manufacturing.

7 Conclusions

First, the findings demonstrate that remanufacturing is not necessarily a green business; so that, a Life Cycle Analysis (LCA) should be included, focusing on the reconstruction process. Second, this study identifies a substantial coincidence between the critical success factors of the maquiladoras considered, although one of the addressed companies is not an Original Equipment Manufacturer (OEM); highlighting the power of the human factor. Third, the companies apply different ways encouraging the developing of the right environment, which contributes preserving its status as a world-class company. Finally, it can be concluded this productive system requires workers with extensive experience in the process, advanced technical skills, and continuous training,

which is in agreement with a previous study developed from another approach [17]. As a result, the companies are concerned about to retain their employees; because of this, they have created opportunities for professional growth in the form of plans for development. These companies have very low staff turnover rates, avoiding the implied cost of losing an employee.

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