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Applying Reverse Supply Chain Optimization in Automotive Industry: Exemplary Case Studies

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ABSTRACT
Growing concern about environmental issues and global competitiveness are prompting manufacturers to adopt more environmentally friendly methods throughout their supply chains. Environmental issues and the sustainability of production are increasingly emphasized by legislative bodies worldwide, and at the same time, stakeholders in these issues require manufacturers worldwide to be aware of the environmental and social impacts of their supply chain activities. Therefore, in order for companies to increase their efficiency and at the same time their sustainability, it is necessary to study in detail the processes that make up their supply chains and to redesign them with the environment and social well-being in mind. Some of these processes are distribution, warehousing, security practices, capacity building such as staff training and social initiatives. This trend has led manufacturers to include Reverse Supply Chain Management in their existing Supply Chain Management. This paper presents two such case studies in the globally critical automotive industry

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I. INTRODUCTION

In recent decades, environmental issues, cost reduction and consumer pressures have become daily problems of Reverse Supply Chain Management (RSCM). Due to environmental problems such as depletion of natural resources, overcrowding of landfills and continuous pressures from national legislators for end-of-life (EoL) product management, fields such as reverse logistics, product returns, remanufacturing and reuse have been rapidly growing and evolving. The adoption of competitive reverse supply chains (RSC) by manufacturing companies contributes to the reduction of inventory management costs, transportation and waste management. At the same time, relationships are built with new customers, due to the ecological reputation that has been created for the company, and a future consumer audience is secured. We therefore understand that RSC is an essential element for a sustainable Supply Chain Management (SCM), since through its activities not only cost reduction and waste reduction is achieved but also value creation is achieved, through the purchase of used or remanufactured products. We therefore conclude that RSC is not only a cost reduction tool for a Supply Chain (SC), but also an important tool for optimization and profit creation, a fact that has sparked the academic and research interest of researchers and experts in the sectors involved [1].

Consequently, RSCM generally involves the movement of recycled, reused and EoL products, along with their information, from end-users/consumers to suppliers and/or manufacturers. RSCM is therefore the collaborative responsibility of consumers and producers to reduce waste through recycling, reuse and proper disposal of unacceptable products, with the aim of environmental sustainability [2, 3].

1.1 Historical Background

RSCs have existed for at least 170 years, but the first systematic records of the reverse logistics phenomenon date back to the American Civil War, between 1861 and 1865. With the end of the American Civil War in 1865, General William Sherman faced a major natural problem: North Carolina's spring rains had swollen the Neuse River, making the transportation of military cargo extremely difficult, leading to the decision to either discard or return older or surplus cargo. The next record we have is in 1872 for the Montgomery Ward furniture company, which adopted a policy that if the customer was not 100% satisfied, they could return the furniture and get their money back [1].

The next development and record we have is again in a time of war and more specifically in World War II, in 1942. At that time, the shortage of metals, plastics and other materials prompted manufacturers to process their surplus materials and waste, in order to create raw materials for production. By the end of World

War II, the US armed forces recycled military equipment worth 6.3 billion dollars, as raw materials for other applications.

The next event that contributed to the gradual acceptance and drew attention to Reverse Logistics (RL) was in 1984, when it was announced in the USA that a batch of the painkiller Tylenol was contaminated. At that time, Johnson & Johnson and McNeil Laboratories quickly withdrew the products from store shelves and replaced them with new, improved packaging, with tamper protection. The event and the rapid response gradually cultivated the concept and acceptance of RL among the population and set new standards for RL.

The years 1991-1996 were crucial for the establishment of RSCs, since it was the period when laws were enacted that essentially made it necessary for a company to adopt a RL or made it necessary for that company to cooperate with another company that had RL as its purpose. In 1991, Germany issued an environmental decree, according to which it made recycling programs mandatory. This decree had set fines and prosecutions for non-compliance and stricter guidelines regarding the management and transportation of hazardous materials, as well as responsibilities for the recovery of hazardous waste. This move by Germany subsequently prompted the United Kingdom to issue a law in 1996, which made producers and transporters responsible for the return and recycling of packaging materials. Then, in 2001, the European Union, taking a step further than the United Kingdom, established a target for the return and recycling of packaging materials at 50-65%, and required its partners to comply with this, so that their cooperation could continue.

The 1998-2000 period is the one when RSC begins to be adopted by businesses and no longer only by production processes. Thus, the research begins on the strategic implementation of RL in everyday life. An important work, which is worth mentioning from that period, is Shad Dowlatsha's "Developing a Theory of Reverse Logistics" [4], in which the author gave a holistic description of RL with 11 factors. He then divided these factors into two categories, as strategic and operational. Strategic factors are broken down into: Strategic Costs, Overall Quality, Customer Service, Environmental Concerns, and Legislative Concerns. Operational factors are broken down into: Cost-Benefit analysis, Transportation, Warehousing, Supply Management, Remanufacturing, Recycling, Packaging.

From 2000 onwards, after the "dot com bubble", which was essentially the period in which e-commerce was established, the RL was now necessary for any business that wanted to have an activity on the internet. As already mentioned, a RSC also manages the information that comes from the consumer/end user and ends up with the producer. Other reasons that made the use of the RL necessary were product returns, wrong shipments or the inability to ship, damaged products, products that were not working and finally the product exchange programs of each company.

Since 2010, the new era of RSC has begun. The introduction of online shopping, smartphones and the general rapid development of technology has pushed companies to create tools that were intended to both analyze returned products and inform customers about the progress of the process. Tools such as tracking the transport truck, automatic analysis of the returned product through sensors, business applications for both employees and customers and the integration of the transport network of both forward logistics and reverse logistics are just some of them.

Nowadays, the European legislation on waste management after 2001 [5] consists of 27Directives-Decisions-Regulations. Accordingly, management is prioritized from best to worst, starting with prevention, then reuse and recycling and finally energy recovery [6], setting specific objectives and responsibilities for managers, whether they are producers or distributors, for the alternative management of waste. The organizations that undertake the management have to carry out in an efficient manner the collection, transport, warehousing, reuse and recycling processes, in environmental terms, of various wastes that were not collected separately for recycling (e.g., batteries) or were collected but not treated responsibly or were collected but only the parts that had economic value were utilized and the rest ended up in the environment or caused pollution. The strategic objectives are[6]:

- Reducing the volume and hazard of the waste produced, as well as limiting its consequences on the environment and health.
- Setting quantitative targets for recycling and other waste recovery operations, within specific time limits.
- The design and establishment of individual or collective return, collection and recovery systems, with the participation of all parties involved, on the basis of "the responsibility of the producer/distributor for the entire life cycle of products".
- Separation of waste at source, in order to achieve a high level of recycling and recovery of materials.
- Information, awareness-raising and awareness-raising of citizens.
- Provision of measures and conditions (permits, certificates, etc.) for the cooperation of those who manage packaging and other products, within the framework of the "polluter pays" principle.

II. METHODOLOGY AND DEFINITIONS

It is important to make a brief reference to the ways in which the academic community and experts in the field carry out research in the field of RSCM. The methods are:

- Mathematical Models (Mathematical Study), which are a research method that is mainly used to optimize the methods and processes that make up the RSC. Through mathematical models, we optimize the route of the means of transport for returning products, the storage of these products in warehouses, the remanufacturing processes, the resale price of products (second-hand/reused products), etc.
- Reviews are a research method, both for the academic community and for those interested in the field of RSCM, in which the reader can read the analysis and conclusions of a researcher in the field of study.
- Case Studies are research conducted on a specific application of RSCM, such as a case study on the management of aluminum from the collection stage to the recycling stage.
- Literature Review (Survey) that is conducted with the aim of gathering and evaluating the literature that currently exists on a topic that is being studied, such as a literature review on RSCM.

Lai et al. [7] investigated six areas of RL, which are waste management, recycling, reuse, material recovery, reprocessing and design. Another area of RL is inventory management. The study of these areas, the solution of their problems and the design are done using various approaches, such as: Conceptual and descriptive types of modeling, Linear and mixed integer programming (MIP), Nonlinear programming methods, Convex and concave programming, Dynamic programming, Queuing models, Markov decision process, Graph theory, Game theory, Fuzzy logic, Simulation modeling, Multi-criteria decision making (MCDM) approaches, Artificial Neural Networks (ANN), Piecewise Interval programming, Dynamic regression models, Statistical modeling, Bayesian belief networks with interval probabilities, Engineering economics techniques, Combining input–output analysis and Laplace transforms, Theory of production frontier, or Institutional theory. For example, Linear Programming is used to solve design and planning problems in RL/CLSC, Fuzzy Logic for decision making, and game theory for costing and orientation problems.

In the literature, various definitions of RSCM have been given. Some of them are by Prahinski and Kocabasoglu [8], who defined RSCM as follows: "RSCM is the effective and optimal management of the actions required to retrieve a product from the consumer for either proper disposal or value recovery". Chen et al. [9] define RSCM as: "The planning, implementation and control of the effective and efficient flow of raw materials, semi-finished products and related information from the point of consumption to the point of origin to re-acquire value or be disposed of". RSCM is divided into core fields and areas of interest, which can belong to several fields simultaneously. The main fields are: Reverse Logistics, Closed Loop Supply Chain, Remanufacturing, Reverse Supply Chain, Refurbishment, Reuse, and Recycle. The areas of interest are: Designing and planning of RSC, Empirical and analytical study of RSC, Production planning and control of RSC, Coordination and Decision Making and Performance evaluation of RSC, Product Life-Cycle Management, and Outsourcing & Offshoring.

2.1 Closed Loop Supply Chains

Closed-loop supply chains (CLSCs) have attracted much attention from industry and academia over the past two decades. CLSCs include both forward supply chains and reverse supply chains [10]. The purpose of a CLSC is not only to meet consumer demand but also to be able to manage the reverse process, efficiently handling product returns from customers and to be able to add value through recycling the product or part of it [11]. A product can be returned at any point in its life cycle and this must be foreseen by the chain management, since a product whose value can be recovered without being fully recycled adds value to that product. We therefore understand that the use of a closed-loop supply chain encourages manufacturing companies to reduce the environmental impact of their production processes [12].

The SC starts from the supply of raw materials to the producer (supply) and continues to the production of the product (production) and the transport-storage-distribution (distribution), to end up with the consumer for use (use). Then the process of the product's reverse course begins to recover its value, through the processes of the RSC or appropriate disposal. The RL therefore begins at the point of collection of the product from the end users (collection), and then these products are sorted into those that can be recovered and those that must be discarded (disassembly-sorting-testing). Those that will be discarded will be divided into those that will go to landfills and those that will be incinerated (incineration). Products that can recover value are divided into:

- those that will be reused-resold after repair (reuse) and then redirected back into the SC flow;
- those that will go through the process of refurbishment, remanufacturing and demanufacturing, i.e., the sorting of parts that can be resold separately, and will also return to the SC flow;
- those that will be recycled and returned as raw material to production.

The design part is connected to almost all stages, which is because the design of a product must take into account its entire life cycle, both during its use by consumers and during its processing by the RSC. This is called Product Life-Cycle Management [13] and as mentioned previously belongs to the areas of great interest in RSCM.

We see that when a company adopts the CLSC model, it has a complete picture of both the life and management of its products and the processes that make it up. The CLSC also provides the company with information for improving products, in order to optimize its processing, that is, there is a feedback of information. Despite this fact, for some companies this model is not suitable and it is more advantageous for them to outsource the RSC processes to third parties. This is the reason why closed loop RSCs are mentioned separately from general RSCs.

2.2 Reverse Supply Chains

The RL starts from the point of return of the products, which could be an external collection bin or the point of original sale itself (retailers), and follows a path to the entities that make the collection, whether these are resellers or original sellers. Then the products go through the process of control and evaluation, so that they are divided into those that will be resold (re-stock), will go through the refurbishment process, will be broken down into pieces that have value and will be recovered, and finally into those that have no immediate value (scrap) and the recovery of value will take place after their recycling. All stages are connected to each other through the transport channels of RL and the storage and holding areas (warehouses).

A phenomenon that exists in the field of RSC is that resellers as well as original sellers (retailers) are also the ones who sort the returned products. Beh et al. [14] studied the importance of businesses involved in the resale (resellers) of clothing and concluded that the second-hand market not only contributes to the reduction of this waste, but, because it has direct contact with consumption, can bring profits. Tyagi et al. [15] in their research identified four factors that significantly contribute to the reliability and efficiency of a RSC. These factors are the handling of the products, the facilities, the information they provide and its accessibility to customers. In addition, an effective RL network together with an easy returns policy is the key to a reliable and efficient RSC.

2.3 Reverse Logistics

According to the American Reverse Logistics Executive Council, RL is defined as: “The process of planning, implementing, controlling, and efficiently moving raw materials (goods in process), finished products, and related information from the point of consumption to the point of origin for value addition or appropriate disposal” [16, 17].

Generally, RL starts from the collection of used products or returned products from consumers/end users and ends with the decision for their subsequent management, which can be remanufacture, repair, recycle and/or appropriate disposal (scrap). The importance of the field of RL is particularly important and of great interest to the society, and this is evident from the abundance of scientific papers and articles that are constantly published [18 - 20].

A study by statista.com [21] on e-commerce returns in 2020 showed that the cost of returned products was $550 billion, 1.5 times higher than the corresponding cost in 2017. In order to reduce the operating costs of the RL network, it is very important that the product collection points are located in both an optimal and accessible location for the end user. According to Guide & Van Wassenhove [22], the nature of RL has now changed from a purely cost-minimizing process to a profitable process.

2.4 Remanufacturing

Interest in EoL activities in industry and academia is growing, due to increased economic and regulatory pressures that push businesses to maximize material efficiency and control their waste. One of these processes is Remanufacturing. There are several definitions of remanufacturing [23 - 26]; indicatively, according to the BSI BS 8887-2:2009 standard, remanufacturing is the process of returning or restoring a used product to at least its original functional performance, while providing an equal or better warranty than a new product [27].

Remanufacturing differs from other reuse processes, such as repair or lower-quality reconditioning, in that the final quality of the product is as good as new. Remanufacturing not only recovers the materials but also retains the energy that was used to create them from raw materials [28]. This means that the energy used to convert raw materials into useful materials remains in the material, as it does not return to raw materials but remains as it is. This has the potential to reduce production costs while minimizing environmental impact by reducing raw material consumption and waste generation. Research conducted by Global Industry Analysts showed that the global remanufacturing industries had total profits of around US$100 billion in 2010 [29].

Remanufacturing may seem like a simple solution for companies that want to minimize their financial costs and environmental footprint, while delivering high-quality products, but in reality, it is a process with high investment costs. Remanufacturing can cost more than the corresponding cost of recycling and depends on factors such as demand, design and condition of the returned product. If we also include the factor of uncertainty, we understand that the company must study this model thoroughly in terms of its sustainability, both at the strategic planning level and at its operational stage. The tools used for the evaluation are of the same nature as those used in RL, namely using qualitative, quantitative and mixed variables in decision models.

Parkinson and Thompson [26] conducted research on the processes that make up remanufacturing and concluded that there are eight sequential steps:

- Entrance diagnosis of the system that occurs when a product first arrives at the unit responsible for remanufacturing; this process uses technologies, such as an embedded memory in the product, to discover its operational history up to the day of delivery; for example, the operating hours of a machine can be diagnosed and based on this an initial picture of its condition can be created.
- Disassembly is the process in which the product is disassembled into all its parts and those that can be reused in the future are separated.
- Cleaning these parts from dirt and residues.
- Inspection follows the cleaning; in this process, all parts are examined to find the functional ones, those that have value as spare parts, those that need repair and those that will follow the path of disposal.
- Recondition is the potential maintenance/repair of the product part.
- Upgrade is the replacement of the damaged part of the product with one that is technologically superior to the previous one.
- Replacement will use the same part of the product, either bought again or collected from other similar products.
- Reassembly is the last stage, where the product acquires its original functional form and is ready to be promoted back to the market.

From the above we understand that remanufacturing is a particularly important process for the RSC. Through it, the SC is supplied not only with spare parts but also with information about the use and life cycle of the product. The functional parts that are recovered from non-functional products that do not require repair are re-supplied to the second-hand market, and through their value they provide new income to the company. An example is the automotive industry, where the use of second-hand parts is particularly common.

Remanufacturing differs from manufacturing in terms of the ability to find replacement parts and the ability to predict demand. A product that has been remanufactured cannot be marketed as new. Its demand is determined not only by the final quality of the product, but also by the consumers' perception of the risk they will take by purchasing it at a price other than the subjective one. Wang and Hazen [30] investigated what can influence consumer perceptions of value and risk, and concluded that subjective value is influenced by the quality, cost, and "green" nature of the product, while subjective risk is influenced by the quality and purchase cost.

2.5 Product Recovery Systems

As product recovery systems we refer to the processes to which returned products are subject, such as repair, reuse, remanufacturing, recycling and refurbishment, after the end of their practical useful life. Because remanufacturing is a large and complex process, it was analyzed separately in the previous subsection. In general, the return of EoL products is a practice that focuses on reducing the waste generated, and is of primary importance for sustainable development. Returned products can be divided into four categories:

- EoL Returns, which are products that have been returned from the market, in order to avoid environmental or commercial damage; these returns are usually mandated by some legislative framework.
- End-of-Use (EoU) Returns, which are products that are returned by the user, when it is determined that there is no further reason for their use by the user; EoU products are not damaged products and can therefore be resold, either directly in the secondary market (second hand market / aftermarket) or remanufactured and follow the corresponding path.
- Commercial Returns are those returns that are directly related to the sales process; these returns include product returns due to warranty, damage during transport and/or recall by the company.
- Re-Usable Components Returns, which are products that were used to transport other products; these can be glass bottles, containers, wooden pallets, etc.; excluding those that were used to transport food or chemicals, we therefore understand that this category of products does not require special processing after return.

Refurbishment

Parkinson and Thompson [26] defined refurbishment as the process of processing old equipment with the aim of enhancing its performance to a satisfactory level at the lowest possible cost. A common example in everyday life is the advertising of companies that sell laptops at particularly low prices, with quite old hardware that they have obtained from the second-hand market. Through refurbishment, the company makes a profit, since the market value of the used equipment is relatively low, while its resale value is considerably higher.

Upgrade

Parkinson and Thompson [26] defined upgrade as the process by which a product acquires upgraded/enhanced capabilities. Some examples of upgrades are desktop upgrades and car upgrades (engine-peripherals), with the aim of reselling them. Naini and Shafiee [31] proposed an upgrade model with three variables to find the optimal upgrade and selling price. These variables are age, the upgrade performed and the new warranty. The same variables could also be used to evaluate refurbishment. An issue that concerns and needs special study is the issue of market cannibalism. By the term market “cannibalism” we mean the preference of users to buy from the second-hand market. This hinders the sales of new, perhaps technologically superior, products.

Reuse

Parkinson and Thompson [26] defined reuse as the process in which a product is maintained in the condition in which it was acquired. The product will not be destroyed or recycled but will be resold as is. Research by Matsumoto et al. [32] on the Japanese re-used market showed that due to the relatively good quality of second-hand products, whether EoL or EoU, the second-hand market experienced rapid growth, both in terms of product quality and efficiency, as users preferred this market over new. As a result, carbon emissions and the rate of landfill growth decreased.

Recycling

Parkinson and Thompson [26] defined recycling as the process of recovering materials/raw materials from discarded products. This process comes after the sorting phase in a waste management facility and concerns products for which the only option to recover their value is to use them as raw materials.

Warranty – Risk

The user who chooses to purchase a product from the RSC is faced with uncertainty, both regarding the condition of the product and its history of use and maintenance by previous users. The history may not always be unknown, but the uncertainty of the product’s durability always worries the new user. For this reason, sellers, as a way of promoting and ensuring quality, offer particularly rich warranties [33]. Regarding products that come from the RSC and have direct industrial application, such as used machine tools, their safety must be checked and certified by official bodies (e.g., Occupational Safety and Health Administration - OSHA of the USA, or EU-OSHA for the European Union, [34]).

2.6 Outsourcing

Forecasting the demand for a product is a technique used in both Forward Supply Chains (FSC) and RSC, but in FSC it is comparatively easier, since the researcher does not have to deal with the uncertain situation of a returned product. This makes the RSC more thoughtful, which in turn makes it necessary to adopt and implement return policies, which are carefully studied and designed to make the collection of returned products as efficient as possible [35]. Coordination between partners/collaborators along the chain also contributes significantly to this [36]. However, the golden mean between customer service, regulatory and operational requirements and market competitiveness is difficult to achieve. While RSC is considered a cost-driven activity by companies whose main activity is forward logistics, it is becoming necessary due to regulatory and environmental concerns [37].

The adoption and implementation of a RSC faces several difficulties that arise mainly due to ignorance of the industry. Some of them are:

- The availability of financial resources [38, 39].
- The risk of adopting a RSC [40, 41].
- The rejection of returned products [42, 43].
- The outsourcing of RSC activities [44].
- The integration of forward and reverse SCs [45].
- The difficulty of evaluating overall performance [46].
- The existence of information technology (IT) infrastructure [47].
- The return policy [48].

- The availability of technology [39].

Due to the above challenges faced by companies that want to integrate RSC into their activities, many are investigating the possibility of outsourcing these activities. Therefore, many companies choose to outsource part or even all of their RSC, depending on the business model [49]. In this way, companies have the opportunity to focus more on their core activities and reduce their investment costs, while interacting with their customers in a dynamic business environment [50]. Therefore, many companies choose to outsource their RSC activities, since these are not part of their core business. Also, many companies choose to outsource their logistics activities. Thus, RSC managers have to face challenges, such as minimizing waste, creating return facilities and controlling the costs of the processes, at the same time that the uncertainty of product collection significantly contributes to their quality [51].

So, knowing the above, we can define outsourcing as: “The use of external sources to carry out activities” [52]. Organizations that choose to adopt the RSC must choose, depending on their business model, whether to outsource all or part of their RSC activities to third parties [49, 53].

In the 1980s, organizations “used” outsourcing as a tool to reduce costs through service-related processes [54]. In the 1990s, this idea evolved and companies now used it to focus on their core activities, increasing their revenues [55, 56]. It is now accepted by researchers that if a company is not particularly efficient in an activity, while this is not a core business activity and at the same time it is not given an advantage over the competition, this specific activity should be assigned to third parties, that is, it should be outsourced [57, 58].

In general, the reasons for outsourcing the activities of a RSC are cost, quality, flexibility, responsiveness and access to the latest technologies offered by the collaborating organizations [59 - 61]. Ko & Evans [62] emphasized that a specialized RSC network for collecting, sorting, inspecting, rejecting and processing returned products requires an equally specialized IT department, as well as employees. Such an outsourced network would offer not only reduced costs for the company but also increased quality of the final returned products, compared to the corresponding ones if the company undertook them itself [2, 63 - 65].

Outsourcing is an important decision that a company/organization has to make, especially when it comes to returned products, where the process becomes more complex as we integrate sustainability elements, which over the years become more and more necessary [61, 66]. In a recent study, Agrawal & Singh [67] report that outsourcing is a common and global phenomenon in companies, and especially in companies operating in the field of RSC. The reasons why this happens are:

- The company can focus on its core activities.
- There is a financial benefit from outsourcing.
- Third-party companies often offer better services, since they have specialized management systems and procedures.
- There is a reduction in investment costs for RSC activities.
- Greater flexibility is provided.
- Better customer service is provided.
- The companies that undertake these activities are responsible for the entire life cycle of the product.
- The companies that undertake the activities may have better environmental management, since they specialize in this sector.

Finally, it was found that there is a belief that all of the above contribute directly or indirectly to the economic performance of the RSC.

III. CASE STUDIES

Considering the extent of the automotive industry globally and the related massive usage of common as well as rare resources, this work presents two case studies that constitute interesting and exemplary applications of RSCM.

3.1 The Battery of Audi Q5 Hybrid System

The present case study, conducted by Wegener et al. [68], is of particular interest because it is conducted from the perspective of an Original Equipment Manufacturer (OEM). The fact that the product is processed by an OEM provides a great advantage over a 3rd Party Remanufacturer (3PR), because the OEM knows all the procedures and steps that must follow in order to fully or partially process the returned product. It is important to note, however, that a 3PR would reach the same result through reverse engineering and record the same steps, over time, at the end of processing this product. The study analyzes all the procedures for the complete disassembly of the battery system of an Audi Q5 Hybrid System/VW Jetta Hybrid, so that it can then be recycled.

The LithoRec Project

The LithoRec Project [69] is a German project for the recycling of Lithium-ion (Li-ion) batteries, which studies all aspects of the processing and subsequent recycling of batteries of this technology. It has developed a series of procedures-steps for the safe and correct processing of returned batteries, so that they can ultimately be recycled.

The nine steps from possession to final recycling of the battery are as follows: (1) Possession of Lithium-ion battery technology, (2) Discharge, (3) Disassembly, (4) Coarse Shredding, (5) Separation/Sorting No.1, (6) Crushing (Fine Crushing), (7) Separation/Sorting No.2, (8) Treatment/Recycling, and (9) Raw Material.

Initially, it is particularly important to discharge the battery, so as to avoid working on it when it is at 400V, since there is a risk from both the high voltage and any chemical reactions. This is followed by the disassembly of the battery block, in order to separate the battery cells from the remaining parts. This is followed by the shredding of the disassembled parts and the separation/sorting of the derivatives, into those that will be recycled for raw material and those that will be crushed. The derivatives of the crushing are separated again and recycled. All the recycled raw material can now be used again, to create new batteries.

The Battery

Generally, the battery systems of electric vehicles (EV) are divided into two categories: those used in purely electric vehicles and those used in hybrid vehicles, i.e., those that also have an internal combustion engine (ICE). In its general form, the battery system of both types is similar, if not the same. In both types, the batteries (battery cells) form stacks/modules, which are connected to each other, creating larger arrays, which are then connected to their heating and cooling systems (different from the vehicle's air conditioning system). All together are then connected to the battery management system (Battery Management System, BMS) and then placed in an electrically insulated case. Then the power electronics are connected and now we have the complete vehicle battery system.

The battery system of the Audi Q5 Hybrid is no different from the above. It is a battery system for hybrid vehicles, which is manufactured by Audi AG within the general framework of the Volkswagen Group, and this is the reason why one also encounters it in the VW Jetta Hybrid model. It consists of four battery modules, a battery management system (BMS), as well as the necessary power electronics. Its dimensions are 50 cm x 70 cm x 15 cm, with a total weight of approximately 35 kg. Its nominal capacity is 5 Ah and its nominal voltage is 266 V. The four battery modules include 18 batteries each (72 in total) connected in series with an individual nominal voltage of 3.7 V.

The Disassembly Process

The disassembly of the battery system starts at the system level and ends at the battery cells. At an industrial level, the sorting of the parts resulting from the assembly does not need to be done for each part separately, but only at the material level, i.e., metals, plastics, batteries, etc. This saves time during the recycling process, since no further sorting is needed, as the recycling of metals is done in the same way, plastics in the same way, etc. Thus, the system does not need to be completely disassembled, only its main parts. The disassembly is done manually, with power tools, in order to obtain the battery cell, so that it can then be followed by a two-step shredding and sorting of the pieces for further processing and recycling.

Upon completion of the disassembly process and after recording its steps in detail, the authors [68] reached conclusions, which concerned both the design of the battery system and the safety measures that should be taken, so that the entire process is carried out safely for the worker. They also designed and proposed the working environment that could be adopted in the factory where the disassembly process would take place, both at an initial stage, without automation, and at a more advanced stage, with the use of automation and robots.

Regarding the design of the battery system, the study showed that there are elements that contribute to increasing the complexity and difficulty during the disassembly process. One of these is that there are different types of screws in the system, resulting in additional time spent on selecting the appropriate tool. Also, the screws are not always easily accessible, but require moving and rotating the system. Another issue is that of accessing parts that are not easily accessible through automated systems, such as the BMS connection cables. This at an early stage, where returns are few, does not affect the final result, but as hybrid and electric vehicle technology becomes more accepted, the volume of returned battery systems that will have to be processed will continue to increase, which requires minimizing disassembly time and creating a task that is as automated as possible. The authors proposed either two people or one person and a robot (the KUKA LWR) to carry out the disassembly process.

Regarding safety at work, it is emphasized that the main risk is that of the battery voltage and the chemicals found in the batteries (battery cells). It is therefore necessary:

- that the battery is discharged, so that there is no ignition of the electrolytes in the event of damage to the battery;
- that the human resources working on the battery have tools that offer safety from voltages;
- that there are tools in the immediate working environment to deal with both ignition and injury.

It is also important for the safety of the human resources that the robot has sensors, so as to avoid any accident during simultaneous work.

A workstation was proposed for the work environment. The battery system would arrive by conveyor belt to the main disassembly area and from there either the two workers or one worker and the robot would take over. The tools should be close by to avoid movement, as would the area where the materials would be collected. The materials would be divided into four categories: electronics, ferrous metals, battery packs, and other materials. The battery packs would then be transferred to a second workstation for further processing or shredding and separation/sorting for recycling.

Commentary

By the end of this case study, we are able to understand the importance of RSC and Reverse Engineering in the production process. Through the operations of the RSC we are able to:

- recover materials, thus avoiding their new purchase;
- reduce the waste generated, through their recycling;
- properly manage hazardous waste, such as battery electrolytes;
- improve the design of the products produced, through Reverse Engineering;
- optimize the processes and processing of returned products.

For Reverse Engineering more specifically, we see that it is not only a process used by 3rd Party Remanufacturers, Recyclers, Service Providers, but something that the manufacturing company (OEM) itself can use, in order to improve its product and optimize the services it provides throughout the product life cycle, such as maintenance (service), repairs (remanufacturing), disassembly, etc. Third Party companies use Reverse Engineering mainly to learn the processes required to provide EoL services for products, especially in the case where there is no direct collaboration with the OEM.

3.2 The Proton-Exchange Membrane Fuel Cell

This case study will demonstrate how, by creating a multi-criteria optimization model, it is possible to design a “near-optimal” and sustainable fuel cell recovery network for automotive usage in the capital of Saudi Arabia, the city of Riyadh.

As the renewable energy industry develops and countries and people become more environmentally conscious, technologies such as hydrogen-powered vehicles, among others, will become increasingly popular. In the future, the demand for hydrogen-powered vehicles is expected to increase. The same applies to the vehicle models available for sale [70]. In the automotive market at the time of this case study, the available hydrogen-powered vehicles were: the Toyota Mirai, the Honda Clarity and the Hyundai Tucson.

The technology on which hydrogen-powered vehicles are based is the proton-exchange membrane fuel cell (PEMFC) technology. These batteries use hydrogen to provide electrical power through an electrochemical reaction. This reaction requires the use of Platinum (Pt) as a catalyst. However, due to the rarity of the element, the recovery of these batteries after their EoL has proven feasible, and more specifically their remanufacturing. The recovery of these batteries is not only driven by environmental needs, such as the conservation of Platinum, but also by the economic benefits that can arise from product recovery and remanufacturing [71]. Also, with the consolidation of the use of hydrogen vehicles, future legislation will require producers to be responsible for the management of their future waste (Extended Producer Responsibility, EPR), which makes this case study particularly important.

This case study has some features that make it different from the existing ones. It uses factors that are not taken into account in other studies, such as the satisfaction of social responsibility on the part of the company (corporate citizenship) at the expense of economic profit (economic profitability). Also, real maps (Google Maps) are used to calculate the actual distance between the points of the network, which helps the reliability of the study [72].

The Fuel Cell Stack

The fuel cell stack studied is the General Motors (GM) 80 kW hydrogen vehicle fuel cell stack. The main components required to power a hydrogen vehicle are: Oxygen supply, Hydrogen supply, fuel cell stack, and cooling system. Of these, the one that is of the greatest importance and contributes substantially to the power system’s useful life is the fuel cell battery. The fuel cell technology is the Proton-Exchange Membrane (PEM), which is particularly attractive in terms of remanufacturing.

A fuel cell battery consists of many individual fuel cells that produce separate current, which is transferred by jumper cables to the current collectors and then to the vehicle's electric motor that provides the necessary power. The necessary power demand is what will determine the number of fuel cells in the battery. The battery examined in this study consists of 200 cells. The fuel cells split hydrogen atoms into a proton and a free electron with the help of platinum as a catalyst.

Theoretically, fuel cell battery systems have an infinite lifespan, but their useful life depends on two factors:

- *Catalyst performance*: Platinum as a catalyst begins to degrade after two years of normal/daily use in vehicles. In practice, the useful life of such a catalyst in fuel cell battery systems for vehicles is between four and six years of normal use.
- *Vehicle useful life*: The average useful life of a vehicle is approximately ten years. As a result, the useful life of fuel cell batteries, no matter how much their technology develops, has no real reason to exceed these years.

In essence, the above two factors, together with the scarcity of platinum, contribute to the need to create processing structures for fuel cell technology batteries.

Geographical Data

Saudi Arabia is one of the largest oil-producing countries and relies mainly on oil to meet its needs. However, it has set a goal by 2030 to reduce its dependence on oil and shift to more sustainable technologies and renewable energy sources.

The city for which the case study [72] was conducted is Riyadh, the capital of Saudi Arabia. Due to the high population and the lack of adequate public transport infrastructure, the number of vehicles in the city is in the millions. The city is divided into 16 geographical districts, all 16 of which will be considered as a source for the collection of EoL PEMFC batteries. The collection will take place at specific locations, specifically at SACO stores, which collaborated with the authors [72] and provided them with information not only on the locations but also on their storage capacity and the costs involved. SACO stores are a chain of stores for the provision of general-purpose products (multi-purpose store), which has stores in all 16 geographical districts of Riyadh. The locations for the construction of remanufacturing plants, due to certain restrictions imposed by the Saudi Industrial Property Authority (MODON), cannot be freely chosen, but must be within the city's three industrial zones. MODON also provided the authors with the construction costs of the remanufacturing plants by region.

Design-Operational Analysis

For the design of the RL Network, a multi-objective mixed integer linear model was created, which represents the recovery network of the RSC under study. The purpose of the model is to minimize the costs of RL, environmental factors, such as CO2 emissions, social aspects, such as jobs, and to maximize social benefits. More specifically, the model minimizes:

- the collection costs,
- the transportation costs,
- the collection center costs (fixed cost for collection centers opening),
- and the remanufacturing center costs (fixed cost for remanufacturing plants opening).

At the same time, it minimizes CO2 emissions. The model also attempts to maximize social benefit by creating a RL network.

The model decides which of the collection centers will be opened to receive the returned products and which location will be selected for the remanufacturing plants. The distance between the demand source market, the potential collection centers and the potential remanufacturing plant locations is known and specific, and it has been calculated using Google Maps. The CO2 emissions, i.e., fuel consumption, are proportional to the distance traveled during the collection and transportation processes. The final RL network consists of 19 demand points, 24 collection centers and two remanufacturing plant locations. Along with the model, three assumptions were made for the operation of the network, which are:

- Only one remanufacturing unit is needed with known location and capacity.
- One product (single item).
- All collected products will be transported to the remanufacturing unit for further processing.

Model Solution

To solve the model, the authors Alkahtani and Ziout [72] based their model on the International Energy Agency (IEA) forecasts for hydrogen vehicles for the period 2015 to 2050. The three scenarios on which the research was based are the following:

- Optimistic scenario, in which hydrogen vehicles constitute 10% of all vehicles in the city.

- Mid-range scenario, in which hydrogen vehicles constitute 5% of all vehicles in the city.
- Pessimistic scenario, in which hydrogen vehicles constitute 0.1% of all vehicles in the city.

In addition to the scenarios, additional assumptions that were taken into account are as follows:

- The expected life of the batteries is five years.
- All 16 geographical areas of Riyadh are involved, as well as the annual expected number of EoL battery returns per area.
- The usual means of transport for the city will be used for transportation, namely: (a) small pickup vehicle for transportation from the source market to the collection centers; (b) small truck for transportation from the collection centers to the remanufacturing plants.
- The input parameters for potential collection centers are provided by SACO.
- All distances were calculated for actual routes via Google Maps: (a) for distances between source market and collection center; (b) for distances between collection center and remanufacturing plant.

At this point it should be mentioned that multi-criteria optimization problems have several feasible solutions, but none can simultaneously optimize all objective functions. For this reason, the Pareto solution was used, according to which, the most efficient solution is the feasible one that cannot be further improved.

Results

The ε-constraint method was used for the results of the mathematical model and the GAMS (General Algebraic Modeling System) system was used to generate the Pareto solutions. The results produced were for each scenario:

- The results of the optimistic scenario in the case of multi-criteria optimization (case 1) are the creation of collection centers in districts 1, 2, 3, 4, 6, 7, 8 and 9, as well as the district 2 for the creation of the remanufacturing plant; the total cost of this solution is 14,552,183 SAR (Saudi Arabian Riyal). For the case of the Pareto solution (case 2), it is the creation of collection centers in districts 1, 3, 4, 8 and 9, as well as the creation of the remanufacturing plant in district 3, with a total cost of 13,818,836 SAR.
- The results of the mid-range scenario in the case of multi-criteria optimization are the creation of collection centers in districts 1, 2, 3, 4, 6, 7, 8 and 9, as well as the district 2 for the creation of the remanufacturing plant; the total cost of this solution is 14,184,907 SAR. For the case of the Pareto solution it is the creation of collection centers in districts 3, 4 and 9, as well as the creation of the remanufacturing plant in district 3, with a total cost of 13,818,836 SAR.
- The results of the pessimistic scenario in the case of multi-criteria optimization are the creation of collection centers in districts 1, 3, 4, 6, 7 and 8, as well as district 2 for the creation of the remanufacturing plant; the total cost of this solution is 13,318,930 SAR. For the case of Pareto optimization, it is the creation of the collection center in district 4, as well as the creation of the remanufacturing plant in district 3, with a total cost of 13,064,770 SAR.

Discussion

The authors of the study Alkahtani and Ziout [72], examining the results per scenario, concluded that:

- The percentage of the difference in the cost of the optimistic scenario between the first and second case is not large enough to prevent the company from not taking environmental and social factors into account.
- In the optimistic scenario, the model showed that all collection centers would be opened except for 5 (for case 1). They attribute this to the close distance it has to collection center 4.
- For the medium scenario, the network that was formed shows that for case 1, the CO2 emissions are 122,456 kg, while for case 2 they are 135,454 kg. However, case 2 has lower costs. It is therefore a decision of the company whether the decision it will make will be purely based on profit or whether the environmental factor and the social factor will be taken into account, since the collection centers in case 1 are more and therefore more jobs are created.
- For the pessimistic scenario, due to the low number of products, only one collection center needs to be active to meet demand. At this point, the authors consider that the survival of the company is questionable.
- There is a relationship between CO2 emissions and product demand.
- The network cost is directly related to fixed costs and capital costs.

Furthermore, after analyzing the results, the authors Alkahtani and Ziout [72] concluded for the case study of PEMFC battery remanufacturing that:

- The introduction of a PEMFC battery remanufacturing model and the optimization of this model through the procedures mentioned in their paper is feasible.

- A CO_2 emission limit needs to be established to act as an incentive for the company to take environmental and social factors into account.
- Since the cost of the network results mainly from fixed costs and capital costs, the survival of the company mainly depends on the choices it will make regarding these costs (e.g., remanufacturing unit cost).
- The model is able to optimize the network, according to the initial data and modify it as they change.
- In the future, the same model could be modified and used again with real conditions of demand and required quantity of reconstruction.

IV. CONCLUSION

The environmental conditions of the 20th and 21st centuries created the need to study the impacts of SC on the environment and society. The concept of SC Sustainability and Sustainable Development was then created, which aimed at the development of the economy with the simultaneous development of ecological and social awareness. This meant that now the optimization of a SC was not only about economic benefits but also about the impact it would have on the environment and society. From the environmental point of view, SC had to make the best possible use of its raw materials but also be able to manage its own waste to the maximum extent possible. From the societal point of view, SC had to take into account the whole of society, by securing new jobs and supporting the local population. Of course, it maintained its goal, which was the financial well-being of each business.

The creation of the RSC was partly a result of the thinking about a Sustainable SC and the thinking about Sustainable Development. Other reasons for the creation of a RSC were the need for feedback from consumers, regarding the products of each company and the support of these by the company. The RSC takes over the reverse path of products and information, that is, from consumers to companies. Regarding information from consumers, the company gains important information regarding the products in question, both from the way they are used and from the damage they experience during their life. Regarding products, the RSC takes over their management after their end of life or after the end of their use. Through the RSC processes, the company expands its business activities by introducing it to the secondary market. The RSC offers economic benefits to the company, since value is created from the returned products that it resells in the secondary market, after having processed them appropriately. Products that do not end up in the secondary market will be recycled and become raw material for the company's production process. This has significant economic benefits since the company will not need to purchase raw materials again. Furthermore, RSC manages both the waste of the production process and the reverse flow, i.e., consumer waste. We therefore distinguish an environmental and social awareness of RSC that is directly linked to the goals of Sustainability and Sustainable Development. In addition, RSC also functions as a tool for optimizing the SC of the company. The information it collects and the materials it recovers contribute to the improvement of the products, the production processes and the financial well-being of the company. Along with the use of specialized planning tools, the company that has an optimized integrated SC (Forward and Reverse) has a significant advantage over its competition, as it has minimized production costs and maximized its profits.

The first case study concerns the processing of a returned product (electric vehicle battery) and how this processing contributes substantially to the improvement of the product and the proper management of hazardous waste associated with it. In this study, through the disassembly process, points were found in the product design that could be improved, in order to facilitate the processing of subsequent products. In other words, we have an improvement of a product throughout its life cycle through information obtained from RSC processes. In addition, we see how the hazardous waste of a product (e.g., battery electrolytes) is properly managed and the recycling process is carried out, with the aim of recovering raw materials that would have been lost in the event of simple disposal.

The second case study does not concern a specific process of RSC but how a product recovery network is optimized, through the tool of mathematical modeling. Thus, after the substantial use of a model and its results, we are able to understand the purpose and effectiveness of this tool in applications related to SCs and the optimization of their networks.

An important tool that was used in these two case studies and is particularly useful for product improvement and process optimization is Reverse Engineering. Through Reverse Engineering in RSC, gaps in product design are found, possible ways to improve them and significant knowledge about their operation is gained. As a tool, it is used both by the producers themselves and by third parties in the RSC. Finally, we conclude that an integrated SC is not necessarily a single entity, but consists (usually) of many smaller chains, managed by different companies and through excellent cooperation between partners, the ultimate goal of a Sustainable Optimized SC is achieved.

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REFERENCES

[1]. Papakitsos, C. 2021. Optimization and Sustainability of Supply Chain: The Application of Reverse Supply Chain - Case Studies [in Greek]. Dissertation, Department of Mechanical Engineering, University of West Attica, Greece. doi: http://dx.doi.org/10.26265/polynoe-1313

[2]. Govindan, K., Palaniappan, M., Zhu, Q. and Kannan, D. 2012. Analysis of third-party reverse logistics provider using interpretive structural modeling. International Journal of Production Economics, 140(1):204-211.

[3]. Bouzon, M., Govindan, K., Rodriguez, C. M. T. and Campos, L. M. S. 2016. Identification and analysis of reverse logistics barriers using fuzzy Delphi method and AHP. Resources, Conservation and Recycling, 108:182-197.

[4]. Dowlatshahi, S. 2000. Developing a Theory of Reverse Logistics. Interfaces, 30(3):143–155.

[5]. Achillas, C., Vlachokostas, C., Aidonis, D., Moussiopoulos, N., Iakovou, E. and Banias, G. 2011. Optimising reverse logistics network to support policy-making in the case of Electrical Equipment. Waste Management, 30:2592-2600.

[6]. Panousopoulou, P. 2014. Reverse Supply Chain and Agile Information Systems: Process Modeling and Application to the Mobile Telephony Industry in Greece [in Greek]. University of Macedonia, Thessaloniki, Greece.

[7]. Lai, K. H., Wu, S. J. and Wong, C. W. 2013. Did reverse logistics practices hit the triple bottom line of Chinese manufacturers? International Journal of Production Economics, 146(1):106-117. doi: 10.1016/j.ijpe.2013.03.005

[8]. Prahinski, C. and Kocabasoglu, C. 2006. Empirical research opportunities in reverse supply chains. Omega, 34(6):519-532.

[9]. Chen, H., Kunnimalaiyaan, M. and Van Gompel, J. J. 2005. Medullary Thyroid Cancer: The functions of raf-1 and human achaete-scute homologue-1. Thyroid, I5:511–521.

[10]. Mishra, D., Gunasekaran, A., Papadopoulos, T. and Hazen, B. 2017. Green supply chain performance measures: a review and bibliometric analysis. Sustainable Production and Consumption, 10:85-99.

[11]. Wells, P. and Seitz, M. 2005. Business models and closed-loop supply chains: a typology. Supply Chain Manag. Int. J., 10:249-251.

[12]. Gutowski, T. G., Sahni, S., Boustani, A. and Graves, S. C. 2011. Remanufacturing and energy savings. Environmental Science and Technology, 45:4540-4547.

[13]. Ming, X. G., Yan, J. Q., Lu, W. F. and Ma, D. Z. 2005. Technology solutions for collaborative product lifecycle management–status review and future trend. Concurrent Engineering, 13(4):311-319.

[14]. Beh, L. S., Ghobadian, A., He, Q., Gallear, D. and O'Regan, N. 2016. Second-life retailing: a reverse supply chain perspective. Supply Chain Management: An International Journal, 21(2):259-272.

[15]. Tyagi, R. K., Dhanda, K. K. and Young, S. 2012. An operational framework for reverse supply chains. International Journal of Management and Information Systems (Online), 16(2):137.

[16]. Rogers, D. S. and Tibben-Lembke, R. S. 1999. Going Backwards: Reverse Logistics Trends and Practices, Vol. 2. Reverse Logistics Executive Council, Pittsburgh, PA.

[17]. Govindan, K., Soleimani, H. and Kannan, D. 2015. Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. European Journal of Operational Research, 240(3):603-626.

[18]. Jonrinaldi, A. and Zhang, D. Z. 2013. An integrated production and inventory model for a whole manufacturing supply chain involving reverse logistics with finite horizon period. Omega, 41(3):598-620.

[19]. Cardoso, S. R., Barbosa-Povoa, A. P. F. and Relvas, S. 2013. Design and planning of supply chains with integration of reverse logistics activities under demand uncertainty. European Journal of Operational Research, 226(3):436-451.

[20]. Nativi, J. J. and Lee, S. 2012. Impact of RFID information-sharing strategies on a decentralized supply chain with reverse logistics operations. International Journal of Production Economics, 136(2):366-377.

[21]. https://www.statista.com/statistics/871365/reverse-logistics-cost-united-states/

[22]. Guide, V. D. R. Jr. and Van Wassenhove, L. N. 2009. OR FORUM—the evolution of closed-loop supply chain research. Operations Research, 57(1):10-18.

[23]. Ijomah, W. L. 2009. Addressing decision making for remanufacturing operations and design-forremanufacture. International Journal of Sustainable Engineering, 2(2):91-102.

[24]. Thierry, M., Salomon, M., Van Nunen, J. and Van Wassenhove, L. 1995. Strategic issues in product recovery management. California Management Review, 37(2):114-136.

[25]. Chari, N., Diallo, C. and Venkatadri, U. 2014. State of the Art on Performability Across the Sustainable Value Chain. International Journal of Performability Engineering, 10(6):543– 556.

[26]. Parkinson, H. and Thompson, G. 2003. Analysis and Taxonomy of Remanufacturing Industry Practice. Proceedings of the Institute of Mechanical Engineering, Part E: Journal of Process Mechanical Engineering, 217(3):243–256.

[27]. Walsh, B., Waugh, R. and Symington, H. 2015. Remanufacturing Study – Circular Economy Evidence Building Programme – Summary Report – 2015. Technical Report, Zero Waste Land.

[28]. King, A. M., Burgess, S. C., Ijomah, W. and McMahon, C. A. 2006. Reducing waste: repair, recondition, remanufacture or recycle? Sustain. Dev., 4:257-267.

[29]. Global Industry Analysts. 2010. Automotive Remanufacturing: A Global Strategic Business Report. Tech. rep., Global Industry Analysts, Inc.

[30]. Wang, Y. and Hazen, B. T. 2016. Consumer product knowledge and intention to purchase remanufactured products. International Journal of Production Economics, 181:460-469.

[31]. Naini, S. G. J. and Shafiee, M. 2011. Joint Determination of Price and Upgrade Level for a Warranted Second-hand Product. The International Journal of Advanced Manufacturing Technology, 54(9–12):1187–1198.

[32]. Matsumoto, M., Nakamura, N. and Takenaka, T. 2010. Business Constraints in Reuse Services. IEEE Technology and Society Magazine, 29(3):55–63.

[33]. Shafiee, M. and Chukova, S. 2013. Maintenance Models in Warranty: A Literature Review. European Journal of Operations Research, 229(3):561–572.

[34]. Baker, R. 2006. Process Safety Concerns Can Arise When Using Refurbished or Newsurplus Equipment. Hydrocarbon Processes, 85(11):73–80.

[35]. Ostlin, J., Sundin, E. and Bjorkman, M. 2008. Importance of closed-loop supply chain relationships for product remanufacturing. International Journal of Production Economics, 115(2):336-348.

[36]. Kumar, R. and Singh, R. K. 2017. Coordination and responsiveness issues in SMEs supply chains: a review. Benchmarking: An International Journal, 24(3):635-650.
[37]. Ravi, V. and Shankar, R. 2005. Analysis of interactions among the barriers of reverse logistics. Technological Forecasting and Social Change, 72(8):1011-1029.
[38]. Morgan, T. R., Tokman, M., Richey, R. G. and Defee, C. 2018. Resource commitment and sustainability: a reverse logistics performance process model. International Journal of Physical Distribution and Logistics Management, 48(2):164-182.
[39]. Lambert, S., Riopel, D. and Abdul-Kader, W. 2011. A reverse logistics decisions conceptual framework. Computers and Industrial Engineering, 61(3):561-581.
[40]. Ferrer, G. and Ketzenberg, M. E. 2004. Value of information in remanufacturing complex products. IIE Transactions, 36(3):265-277.
[41]. Senthil, S., Murugananthan, K. and Ramesh, A. 2018. Analysis and prioritization of risks in a reverse logistics network using hybrid multi criteria decision making methods. Journal of Cleaner Production, 179:716-730.
[42]. Hazen, B. T. 2011. Strategic reverse logistics disposition decisions: from theory to practice. International Journal of Logistics Systems and Management, 10(3):275-292.
[43]. Agrawal, S. and Singh, R. K. 2019. Analyzing disposition decisions for sustainable reverse logistics: Triple Bottom Line approach. Resources, Conservation and Recycling, 150:104448.
[44]. Kushwaha, S., Ghosh, A. and Rao, A. K. 2020. Collection activity channels selection in a reverse supply chain under a carbon cap-and-trade regulation. Journal of Cleaner Production, 260:121034.
[45]. Pedram, A., Yusoff, N. B., Udoncy, O. E., Mahat, A. B., Pedram, P. and Babalola, A. 2017. Integrated forward and reverse supply chain: a tire case study. Waste Management, 60:460-470.
[46]. Han, H. and Trimi, S. 2018. A fuzzy TOPSIS method for performance evaluation of reverse logistics in social commerce platforms. Expert Systems with Applications, 103:133-145.
[47]. Chileshe, N., Jayasinghe, R. S. and Rameezdeen, R. 2019. Information flow-centric approach for reverse logistics supply chains. Automation in Construction, 106:102858.
[48]. Batarfi, R., Jaber, M. Y. and Aljazzar, S. M. 2017. A profit maximization for a reverse logistics dualchannel supply chain with a return policy. Computers and Industrial Engineering, 106:58-82.
[49]. Gunasekaran, A. and Spalanzani, A. 2012. Sustainability of manufacturing and services: investigations for research and applications, International Journal of Production Economics, 144(1):35-47.
[50]. Kakabadse, A. and Kakabadse, N. 2005. Outsourcing: current and future trends. Thunderbird International Business Review, 47(2):183-20.
[51]. Chakraborty, K., Mondal, S. and Mukherjee, K. 2018. Developing a causal model to evaluate the critical issues in reverse supply chain implementation. Benchmarking: An International Journal, 25(7):1992-2017.
[52]. Quinn, J. B. and Hilmer, F. G. 1994. Strategic outsourcing. MIT Sloan Management Review, 35(4):43.
[53]. Kotabe, M. and Zhao, H. 2002. A taxonomy of sourcing strategic types for MNCs operating in China. Asia Pacific Journal of Management, 19(1):11-27.
[54]. Lacity, M. and Hirschheim, R. 1993. Information Systems Outsourcing; Myths, Metaphors, and Realities. John Wiley & Sons, New York.
[55]. Hamel, G. and Prahalad, C. K. 1990. The core competence of the corporation. Harvard Business Review, 68(1):79-91.
[56]. Boyson, S., Corsi, T., Dresner, M. and Rabinovich, E. 1999. Managing effective third party logistics relationships: what does it take? Journal of Business Logistics, 20(1):73.
[57]. Insigna, R. C. and Werle, M. J. 2000. Linking outsourcing to business strategy. The Academy of Management Executive, 14(4):58-70.
[58]. Wu, F., Li, H. Z., Chu, L. K. and Sculli, D. 2005. An outsourcing decision model for sustaining longterm performance. International Journal of Production Research, 43(12):2513-2535.
[59]. Kumari, S., Singh, A., Mishra, N. and Garza-Reyes, J. A. 2015. A multi-agent architecture for outsourcing SMEs manufacturing supply chain. Robotics and Computer-Integrated Manufacturing, 35(1):36-44.
[60]. Li, Y. L., Ying, C. S., Chin, K. S., Yang, H. T. and Xu, J. 2018. Third-party reverse logistics provider selection approach based on hybrid-information MCDM and cumulative prospect theory. Journal of Cleaner Production, 195:573-584.
[61]. Bai, C. and Sarkis, J. 2019. Integrating and extending data and decision tools for Sustainable third party reverse logistics provider selection. Computers and Operations Research, 110:188-207.
[62]. Ko, H. J. and Evans, G. W. 2007. A genetic algorithm-based heuristic for the dynamic integrated forward/ reverse logistics network for 3PLs. Computers and Operations Research, 34(2):346-366.
[63]. Krumwiede, D. W. and Sheu, C. 2002. A model for reverse logistics entry by third-party providers. Omega, 30(5):325-333.
[64]. Huscroft, J. R., Hazen, B. T., Hall, D. J., Skipper, J. B. and Hanna, J. B. 2013. Reverse logistics: past research, current management issues, and future directions. International Journal of Logistics Management, 24(3):304-327.
[65]. Mello, J. E., Stank, T. P. and Esper, T. L. 2008. A model of logistics outsourcing strategy. Transportation Journal, 47(4):5.
[66]. Hubbard, G. 2009. Measuring organizational performance: beyond the triple bottom line. Business Strategy and the Environment, 18(3):177-191.
[67]. Agrawal, S. and Singh, R. 2020. Outsourcing and reverse supply chain performance: a triple bottom line approach. Benchmarking: An International Journal, 28(4):1146-1163. doi: 10.1108/BIJ-09-2020-0498
[68]. Wegener, K., Andrew, S., Raatz, A., Droder, K. and Herrmann, C. 2014. Disassembly of Electric Vehicle Batteries Using the Example of the Audi Q5 Hybrid System. Procedia CIRP, 23:155–160.
[69]. Kwade, A. and Diekmann, J. (Eds). 2018. Recycling of Lithium-Ion Batteries: The LithoRec Way. Springer, Cham. doi: 10.1007/978-3-319-70572-9
[70]. IHS Automotive. 2016. Hydrogen fuel cell electric vehicles and refuelling infrastructure market. IHS Automotive, London.
[71]. Ziout, A., Azab, A. and Atwan, M. 2014. A holistic approach for decision on selection of end-of-life products recovery options. J. Clean Prod., 65:497–516.
[72]. Alkahtani, M. and Ziout, A. 2019. Design of a sustainable reverse supply chain in a remanufacturing environment: A case study of proton-exchange membrane fuel cell battery in Riyadh. Advances in Mechanical Engineering, 11(4):1–14. doi: 10.1177/1687814019842997