National Higher School of Technology
Department of Industrial Engineering & Maintenance

Designing, evaluation and planning of a closed loop supply chain for the automotive industry

Master's thesis in
Industrial Engineering

HASSANI Rania,

Advisor:
Prof. AGGUINI Chafik

Academic year:
2022-2023

Abstract: The automotive industry is facing increasing pressure to adopt sustainable practices in their operations, and closed loop supply chain (CLSC) has emerged as a promising solution to reduce waste and environmental impact. This article presents a comprehensive approach to implementing a closed loop supply chain (CLSC) in the automotive industry. The article covers the design of a CLSC, including reverse logistics, material recovery, remanufacturing, design for recyclability, and supply chain collaboration. The evaluation of a CLSC is explored in terms of cost, environmental impact, and efficiency. Finally, the article discusses planning a CLSC, including stakeholder analysis, resource allocation, and implementation timeline. The proposed approach can help reduce waste, improve resource efficiency, and promote sustainability while maintaining or improving business performance.

Key-words: CLSC, reverse logistics, Closed loop supply chain, automotive industry,carbon emissions.

Proceedings of M. F. E. 2022/2023

Contents

1 Introduction 2
2 State of the art review 2
3 design a closed loop supply chain 4
4 Evaluation a CLSC in the automotive industry 7
5 Planning a closed loop supply chain 8
6 Figures 9
7 Conclusions 9

1. Introduction

Before delving into the topic of closed-loop supply chain management in the automotive industry, it is important to first acknowledge the significant environmental impact that the industry has.The automotive industry is a major contributor to global carbon emissions, with road transport alone responsible for around one-quarter of energy-related CO2 emissions (International Energy Agency, 2021). According to the same source, there were over 1.4 billion motor vehicles in use worldwide in 2020, and this figure is projected to reach 2 billion by 2040. In addition to carbon emissions, the production and disposal of vehicles also result in significant air and water pollution, as well as soil contamination. A European Commission report (2018) indicates that despite some recycling efforts, only around 75% of materials are reused in end-of-life vehicles in the European Union. These figures clearly indicate the urgent need for the automotive industry to reduce its environmental impact. One promising approach is closed-loop supply chain management, which can lead to substantial waste and emission reductions, as well as increased efficiency and cost savings. Studies have shown that the automotive industry is responsible for a large proportion of global carbon emissions, air pollution, water pollution, and soil contamination. For instance, the International Energy Agency (2019) estimates that the automotive industry accounts for approximately 8% of global carbon emissions. These environmental impacts not only harm ecosystems and human health, but also result in economic costs associated with waste disposal and resource depletion. As a result, there is growing pressure on the automotive industry to adopt more sustainable practices and reduce its environmental footprint. In this context, closed-loop supply chain management has emerged as a potential solution to mitigate the environmental impacts of the automotive industry.

Unlike a traditional linear supply chain that follows a 'take-make-dispose' model a Closed-Loop Supply Chain (CLSC) is a sustainable and environmentally conscious approach to supply chain management that accounts for both the forward and reverse flows of products and materials. The forward flow refers to the traditional supply chain processes, which include the procurement of raw materials, production of new products, and distribution to the end customer. The reverse flow, on the other hand, involves the collection, recovery, and recycling of used products and materials, which are then reintroduced back into the supply chain[1]. In the context of the automobile industry, a CLSC encompasses the design, evaluation, and planning of a supply chain that emphasizes not only the production and distribution of new vehicles but also the collection, recovery, and recycling of used vehicles and their components. The forward flow involves the procurement of raw materials, production of new vehicles, and distribution to dealerships and customers. Meanwhile, the reverse flow includes the collection and processing of end-of-life vehicles and their components, which are then recycled and reintroduced into the supply chain as raw materials or components for new vehicles[2]. This approach to supply chain management has gained prominence in recent years as businesses increasingly focus on sustainability and reducing their environmental impact. The use of CLSCs in the automobile industry can lead to significant reductions in waste and emissions, as well as increased efficiency and cost savings. Several studies have shown that the adoption of CLSCs can result in improved environmental performance and increased profitability for businesses in the automobile industry [3].

This thesis aims to explore the concept of closed-loop supply chain management in the automotive industry by examining its unique challenges, identifying potential opportunities, and evaluating its environmental, economic, and social impacts. Specifically, it will focus on understanding how a closed-loop supply chain differs from a traditional linear supply chain, managing high volumes of materials and components, coordinating multiple tiers of suppliers, and meeting strict quality and safety standards. Additionally, this thesis will investigate the potential for using recycled materials, remanufacturing processes, and end-of-life product recovery to create a sustainable supply chain. Finally, it will develop a plan for implementing a closed-loop supply chain in the automotive industry, including identifying key stakeholders, assessing feasibility, and creating a roadmap for implementation.

2. State of the art review

In recent years, many companies in the automotive industry are showing a keen interest in closed-loop supply chains (The closed-loop supply chain is illustrated in Figure 1). This is because they aim to improve their environmental performance and save costs. Various scholars have emphasized the significance of adopting closed-loop practices in the design phase of the automobile product life cycle, as it can provide

Proceedings of M. E. E. G. I. M. - 2022/2023

considerable benefits such as improved environmental performance, cost savings, and customer satisfaction. Our state of the art review aims to explore different perspectives and approaches proposed by scholars and identify potential areas for further research and gaps in this area. According to a study by Alshamsi et al. (2016)[4] , a mixed integer programming model was created to optimize production and inventory planning for the closed-loop supply chain in the automotive industry. The study revealed that the model successfully reduced costs and waste. However, ethical and social factors were not taken into account in the decision-making process.

Wang et al. (2018) [5] developed a multi-objective optimization model to design closed-loop supply chain networks in the automotive industry. The model focused on reducing carbon emissions and costs. However, the study did not consider the impact of uncertainty and risk during the decision-making process.

You et al. (2019) [6] developed a decision support system to optimize the closed-loop supply chain for used electric vehicle batteries. The study found that the system improved the economic and environmental performance of the supply chain. However, the study's limitations were due to the lack of data quality and availability on the supply chain.

In the study by Marques et al. (2020) [7], a system dynamics model was created to analyze the closed-loop supply chain for end-of-life tires in the automotive industry. The model successfully improved the environmental and economic performance of the supply chain. However, the study did not account for the impact of ethical and social factors in the decision-making process.

Wei et al. (2020) [8] developed a multi-objective optimization model to design closed-loop supply chains for lithium-ion batteries in the automotive industry. The study revealed that the model improved the sustainability and profitability of the supply chain. However, the study did not consider the impact of uncertainty and risk in the decision-making process.

Choi et al. (2021)[9] developed a closed-loop supply chain model for the remanufacturing of electric vehicle batteries. The model was effective in enhancing the economic and environmental performance of the supply chain. However, ethical and social factors were not considered in the decision-making process. Taken together, the studies mentioned above offer important insights into the possible advantages and difficulties of the closed-loop supply chain in the automotive industry. Nonetheless, there are still some limitations and gaps in the research, including the necessity for more comprehensive and integrated models that take into account social and ethical factors, as well as the need for more empirical studies to examine the efficacy of these models in real-world scenarios

In the study by Su et al. (2015)[10], a closed-loop supply chain model was created for the remanufacturing of automotive parts. The research found that the model was successful in reducing costs and environmental impact. However, the study did not take into account the impact of uncertainty and risk during the decision-making process.

Abdallah and Diabat (2016)[11] developed a multi-objective optimization model to design closed-loop supply chains for the automotive industry. The results demonstrated that the model was effective in improving the economic and environmental performance of the supply chain. However, the study did not consider the impact of social or ethical factors during the decision-making process.

In the study by Akhtar et al. (2017)[12], a multi-objective optimization model was created to design closed-loop supply chains for the automotive industry, with a focus on end-of-life vehicles. The findings revealed that the model was successful in reducing costs and environmental impact. However, the study did not consider the impact of uncertainty and risk during the decision-making process.

Ijomah et al. (2017)[13] developed a closed-loop supply chain model for the remanufacturing of automotive components. The results showed that the model was effective in improving the economic and environmental performance of the supply chain. However, the study did not consider the impact of social or ethical factors during the decision-making process.

In the study by Jiang et al. (2018)[14], a closed-loop supply chain model was created for the remanufacturing of automotive engines. The results indicated that the model was effective in reducing costs and environmental impact. However, the study did not consider the impact of uncertainty and risk during the decision-making process.

Akar et al. (2019)[15] developed a closed-loop supply chain model for the remanufacturing of automotive batteries. The findings showed that the model was effective in reducing costs and environmental impact. However, the study did not consider the impact of uncertainty and risk during the decision-making process. In summary, the studies reviewed in this state of the art review highlight the importance of closed-loop supply chain models in the automotive industry for

Proceedings of M. E. E. G. I. M. - 2022/2023

improving economic and environmental performance. These models have been shown to effectively reduce costs and environmental impact, particularly in the remanufacturing of automotive components and end-of-life vehicles. However, the studies also reveal a lack of consideration for the impact of uncertainty, risk, and social ethical factors during the decision-making process. Therefore, future research in this area should focus on developing more comprehensive models that take into account these factors for a more sustainable and responsible closed-loop supply chain in the automotive industry.

3. design a closed loop supply chain

Around 7% of the global economy and more than 50 million people worldwide are employed by the vast and complex global automotive company. It creates countless parts and components that are made, shipped, and used in the production of millions of vehicles. Developing a sustainable and profitable supply chain while satisfying customer expectations for reliable and high-quality products is a challenge for the automotive industry. Adopting a closed-loop supply chain (CLSC) (figure 1), that minimizes waste, maximizes the recovery of precious materials, and minimizes environmental impacts is one way to handle these issues. Considerations for designing a CLSC for the automotive firm include product design, logistics, and reverse logistics procedures. We will discuss the key components of a CLSC for the automotive industry and provide guidance on how to design and optimize these processes for maximum efficiency and profitability.

3.1. Reverse logistics

The efficient management of end-of-life products and materials in the automotive industry is crucial in reducing waste, preserving natural resources, and minimizing environmental impact. This is where reverse logistics comes in, which involves the collection, sorting, processing, and reuse of end-of-life products and materials:

Reverse logistics, as the name suggests, refers to the logistics activities of an organization, but in a reversed sense compared to traditional logistics, which goes from the production system to the consumer. This emerging concept has been defined under different terms such as reverse logistics, product recovery management, reverse supply chain, reverse flow, and negative logistics, among others.

Several definitions of this concept exist, but two general definitions have been presented in the literature. The first, proposed by Thierry et al. (1995)[16], calls reverse logistics "product recovery management" and defines it as the management of products, components, and materials that are used or discarded and fall under the responsibility of the manufacturing company. The objective of this management is to extract the maximum economic value possible while reducing the ultimate quantity of waste.

The second definition, given by Beaulieu et al. (1999)[17], defines reverse logistics as "reverse logistics" and describes it as a set of management activities aimed at reintroducing secondary assets into value-added streams. In other words, it involves recovering products, materials, or components to give them a new life or a new use in production streams or different markets.

In the context of the automotive industry, reverse logistics encompasses the management of used or discarded products, components, and materials, such as tires, batteries, engines, bumpers, and mirrors, which fall under the manufacturer's responsibility. The goal is to maximize the economic value of these products while minimizing the amount of waste. Reverse logistics, plays a critical role in closed-loop supply chains that aim to recover and recycle resources. As such, the importance of reverse logistics in the design, evaluation, and planning of closed-loop supply chains in the automotive industry cannot be overstated. However, there are various challenges and opportunities that need to be addressed in order to ensure that the process is successful.

3.2. material recovery

Material recovery involves the disassembly and recovery of materials and components from end-of-life vehicles and parts for reuse in the production of new vehicles or other products. This requires the development of efficient disassembly processes that can recover materials in a cost-effective and environmentally friendly way.The success of material recovery in the automotive industry can be measured by the End-of-life vehicle (ELV) recovery and recycling rates reported by EU member states. These rates reflect the effectiveness of disassembly processes and the extent to which recovered materials and components are reused in the production of new vehicles or other products, con-

Proceedings of M. F. E. G. I. M. - 2022/2023

tributing to a more cost-effective and environmentally friendly circular economy. Figure 2 [18] shows a comparison of ELV recovery and recycling rates among EU member states.In the article, Sundin and Bras [19] define remanufacturing as "the process of returning a used product to at least its original performance with a warranty that is equivalent to or better than that of the newly manufactured product" (p. 17). Examples:

- Toyota's closed-loop recycling system for hybrid vehicle batteries (figure 3) [20], which is a form of material recovery. This system involves disassembling used batteries and recovering valuable materials such as nickel, cobalt, and rare earth metals. The recovered materials are then reused in the production of new hybrid batteries, minimizing waste and reducing the need for new material production. This closed-loop system is designed to be environmentally friendly and sustainable, as it reduces the environmental impact of battery disposal and the need for mining new raw materials. By implementing such systems, Toyota is contributing to a more sustainable future for the automotive industry, and it is a great example of material recovery in action.
- BMW has implemented a closed-loop material cycle for electric vehicle batteries, with material recovery as a crucial component. BMW Brilliance Automotive (BBA), which is a joint venture between BMW and Brilliance China Automotive, has established this cycle to reuse the raw materials nickel, lithium, and cobalt from high-voltage batteries that are no longer suitable for electric vehicles. These batteries come from various sources, including fully and partially-electric development vehicles, test systems, production rejects, and eventually end-of-life vehicles.

  To achieve this,
- BBA is collaborating with a local recycler that uses innovative technology to dismantle retired batteries and recover a high percentage of raw materials such as nickel, lithium, and cobalt from battery cells. These materials are then reused in the production of new battery cells for the BMW Group. By establishing a closed-loop material cycle, BMW is conserving resources and reducing CO2 emissions by up to 70% compared to using newly extracted primary material.

  Once the batteries are returned, they are evaluated to determine their potential for continued use. The BMW Group began using end-of-life batteries with high residual capacity in forklift trucks at BBA plants in China back in 2020. Going forward, the plan is to expand these "second-life applications" to include pallet lifting trucks and stationary energy storage units with charging capabilities.

  If end-of-life batteries do not meet the criteria for second use, they are recycled, and the raw materials obtained in this way are used in the production of new battery cells for the BMW Group. On average, a battery with a capacity of 100 kWh contains almost 90 kg of nickel, lithium, and cobalt, with nickel accounting for most of this amount. This demonstrates how BMW is committed to sustainable practices and reducing its environmental impact.
- Tesla works with Umicore to recycle batteries from their electric vehicles into reusable materials. Umicore's battery recycling technology recovers valuable metals such as cobalt, nickel, and others from the batteries. These metals are then turned into products and byproducts, rather than simply being separated mechanically, allowing for a more efficient recovery process. The recovered metals can be resold to battery manufacturers, including Tesla, as LCO, thereby reducing the need for mining new metals and decreasing the overall environmental impact of the supply chain.

3.3. Remanufacturing

Remanufacturing involves the repair and restoration of components, such as engines or transmissions, to extend their useful life and reduce the need for new production . This requires the development of efficient remanufacturing processes that can restore components to a high quality condition.Sundin and Bras (2005)[19] emphasizes that product architecture plays a key role in the design of a closed-loop supply chain, as it affects the ease and cost of disassembly, remanufacturing, and recycling. They suggested that product modularity and standardization can facilitate closed-loop supply chain operations.

For more than 50 years, General Motors (GM) has been refurbishing automotive components, including engines, transmissions, and fuel systems, by utilizing recycled or salvaged parts. This remanufacturing approach has allowed GM to enhance the lifespan of its

Proceedings of M. F. E. G. I. M. - 2022/2023

products, minimize waste, and conserve resources. To improve the efficiency and quality of its remanufacturing operations, GM has invested in advanced technologies, such as 3D printing and robotics (This involves repairing or replacing any damaged components and reassembling the parts to meet GM's specifications.) . Additionally, GM has explored remanufacturing possibilities in diverse industries, such as aerospace and defense. All in all, remanufacturing plays a crucial role in GM's commitment to sustainability and its mission to reduce its environmental impact. On the other hand Toyota's remanufacturing process involves both refurbishing and remanufacturing, which involve repairing and reusing batteries to extend their life cycle. This helps to reduce the need for new batteries and reduces waste. Refurbishing can include replacing damaged parts or reconditioning the battery to improve its performance. Remanufacturing involves rebuilding the battery using new and recycled parts to create a battery that performs like new. At the same time the BMW Group also has a remanufacturing program that extends the lifecycle of components and reduces waste. This involves refurbishing used parts, such as engines, transmissions, and steering systems, to a like-new condition, and then selling them at a lower cost than new parts. Remanufacturing not only reduces waste but also conserves energy and raw materials, as it requires less energy and resources to refurbish a used component than to manufacture a new one from scratch. The company's remanufacturing program has been recognized with the German Sustainability Award and the Circulars Award for Circular Economy Multinational.

3.4. Design for recyclability

In the literature, the design strategies of "design for disassembly," "design for remanufacturing," and "design for recycling" fall under the broader category of "design for end-of-life" or "design for recyclability." According to Luttropp and Lagerstedt [21], incorporating the design for disassembly strategy in product design not only accelerates the disassembly process but also facilitates the retrieval of a greater proportion of system components. Kuo [22] further emphasizes that the primary objective of design for disassembly is to ensure that a product or system can be disassembled with minimal cost and effort.

According to Coulter et al. [23] and Palmer [24], the viability of remanufacturing depends on the efficiency of the disassembly process, the strength and stability of the demand for standardized parts, and the positive perception of remanufactured content. Designing for disassembly with the provision to replace or refurbish worn parts can result in significant savings, even when factoring in the cost of removing and returning the discarded part to the point of remanufacture [22]. The aim of design for remanufacturing is to bring vehicle parts and sub-assemblies back to an acceptable performance level for re-assembly, enabling the reuse of their materials in their highest value state, thus reducing waste and minimizing the use of virgin resources [23]. While several remanufactured parts, such as alternators, starter motors, and water pumps [25], [26], are available on the market and provide competitive alternatives, they are still largely restricted to the automotive aftermarket segment [23], [24],[27]. Many components are discarded due to slight degradation resulting from wear or corrosion caused by thermal or environmental exposure.

Ashby [28] and Boon et al. [29] have pointed out that incorporating recycled material into products not only reduces the consumption of virgin raw materials, energy, and water, but also helps to decrease waste, air and water pollution, and associated energy usage. Bulucea et al. [30] and Graedel and Allenby have emphasized the importance of avoiding mixed materials in product assemblies as a key principle in designing for recyclability, in order to simplify the process of disassembly, sorting, and material collection. Reuter and van Schaik [31] have supported this idea by suggesting that the number of different plastic and non-plastic materials used in a product should be minimized to improve its recyclability. For instance, BMW has established recycling standards that enable almost 90 kg out of the 162 kg of plastics used in a BMW-3 series to be recycled economically.

BMW is committed to achieving climate neutrality by 2050 and has launched the "Race to Zero" project to achieve this. The circular economy is a crucial part of this project. BMW is focusing on designing its products to be recyclable and reusing materials in closed recycling loops. For example, in China, BMW Brilliance Automotive has developed a system to reuse raw materials like nickel, lithium, and cobalt from retired electric vehicle batteries. BMW is collaborating with a local recycler to recover a significant portion of these raw materials and use them in creating new battery cells. This closed-loop material cycle conserves resources and cuts CO2 emissions by 70% compared to using freshly extracted raw material. BMW aims to maximize the recycling rate for battery raw materials and create a seamless battery traceability system

Proceedings of M. E. E. C. I. M. - 2022/2023

to carefully use all resources. Different levels of recycling exist, according to Allenby and Graedel [32]. The linear material flow system is the lowest level, where all materials used in a vehicle are landfilled at the end of its life (as shown in Fig. 5). In contrast, closed loop recycling is the highest level of recycling, where product components are remanufactured into the same product type without using virgin materials, unless necessary. Closed loop recycling systems are challenging to achieve, making them the ultimate goal in any recycling scenario. If a material cannot be contained in a closed loop, it may be remanufactured into a lower grade substance or combined with first-use material. To maximize the value of materials, they should go through as many different quality levels as possible. For instance, while steel can be remanufactured in a quasi-closed loop scheme, aluminum can be recycled in a fully closed loop system [32]. Virgin steel accounts for over 90% of the steel used in a new vehicle, and recycled steels from automobiles are typically used in civilian structures such as buildings and bridges but not new cars, It's impossible to recycle vehicles 100% due to their product complexity and material diversity. For instance, materials such as steel and plastics cannot be completely remanufactured into products of the same quality as the original. Instead, they can be repurposed into a lower grade product or combined with a different material to create a new substance .

3.5. Supply chain collaboration

In order to achieve a truly circular economy, we need collaboration across the entire supply chain. From design to disposal, every stakeholder needs to be involved and committed to reducing waste and maximizing resource efficiency." - Accenture (Accenture. (n.d.). Driving circular supply chain transformations. Retrieved March 27, 2023,) To design a closed-loop supply chain for the automotive industry, it is crucial to have effective supply chain collaboration. This involves close collaboration with suppliers and partners to create an integrated and efficient supply chain that maximizes material recovery and minimizes waste and environmental impact. Open communication and transparency, data analytics, process standardization, and training and education are key elements of successful supply chain collaboration. Car companies such as Ford have implemented successful collaborative closed-loop supply chain programs that include waste reduction and sustainability best practices, as well as advanced technologies like data analytics and automation to improve supply chain visibility and efficiency. Through these programs, waste and environmental impact can be minimized, and the closed-loop supply chain can be optimized. It should be noted that due to the complexity and material diversity of vehicles, complete recycling may not be possible, but collaboration can help to increase the recovery of valuable materials.

4. Evaluation a CLSC in the automotive industry

Establishing a closed-loop supply chain in the automotive industry is increasingly seen as a sustainable solution to address the environmental and economic challenges facing the industry. This circular approach aims to reduce costs, improve efficiency and minimize the environmental impact of automotive production. However, to achieve these objectives, it is essential to evaluate the performance of this supply chain by focusing on the related costs, the environmental impact and the efficiency of the repair, remanufacturing and recycling processes. In this section, we will use the SWOT matrix to explore the challenges and opportunities of implementing such a closed-loop supply chain in the automotive industry. We will also focus on the costs of setting it up, as well as the environmental impact and effectiveness of this approach. The main indicators for assessing a CLSC:

4.1. Cost

When a company wants to evaluate its closed loop supply chain, it needs to consider the costs of acquiring and disposing of materials, transportation, processing, and refurbishing (sarkis and zhu 2018)[33]. By keeping track of these costs, the company can find ways to save money by reducing waste and becoming more efficient. For example, if the company sees that transportation costs are high, it can try to send fewer shipments or find a way to make transportation more efficient. By tracking the cost of materials, the company can find ways to use less or switch to more sustainable options.

4.2. Environmental impact

environmental impact is a vital factor to consider. This includes measuring the amount of waste and emissions produced by the operations and comparing them to those of traditional linear supply chains. It's

Proceedings of M. F. F. G. I. M. - 2022/2023

also important to assess the environmental benefits of recycling, reusing, and remanufacturing materials, as well as the resulting reduction in greenhouse gas emissions.

4.3. Efficiency

Efficiency, reliability, and flexibility: are key factors in evaluating the effectiveness of a closed-loop supply chain in the automotive industry. Companies must analyze how well the system performs in terms of speed, flexibility, and reliability by tracking metrics such as transportation time, material availability, processing accuracy, and delivery times. By doing so, they can identify areas where improvements can be made to increase efficiency and reliability, as well as enhance the system's flexibility to adapt to changes in demand or supply chain disruptions

5. Planning a closed loop supply chain

Implementing a closed-loop supply chain in the automotive industry requires a comprehensive planning stage. This planning stage is critical in identifying the roles and responsibilities of stakeholders, determining the required resources and investments, and establishing the timeline for implementation. With an effective plan in place, the closed-loop supply chain can be implemented efficiently and sustainably.

5.1. Stakeholder analysis

Stakeholder analysis is an essential element during the planning phase of a closed-loop supply chain's implementation within the automotive industry. As several authors have pointed out (e.g., Zhu et al.; Kim et al)[34], stakeholders refer to any entity that can affect or be influenced by the supply chain. Thus, recognizing and evaluating stakeholders' interests is critical to ensure that they are well accounted for in the closed-loop supply chain's design. Key stakeholders within the automotive industry's supply chain include suppliers, manufacturers, retailers, and customers. According to Govindan et al. [35], effective stakeholder analysis facilitates developing a supply chain design that meets the objectives and goals of all involved parties. Therefore, identifying the advantages and challenges faced by each stakeholder is imperative to guarantee their interests are adequately considered and met when designing the closed-loop supply chain.

5.2. Resources allocation

Developing a closed-loop supply chain in the automotive industry demands substantial investment in various resources such as technology, infrastructure, and human resources. Allocating these resources efficiently is crucial for the smooth progression of the implementation process and to ensure the necessary resources are available at every stage of the process. Various authors, including Pagell et al. and Guide Jr. and Van Wassenhove [36], have highlighted the significance of resource allocation in this process. Technology plays a fundamental role in the closed-loop supply chain as it enables the collection and analysis of data throughout the supply chain. Therefore, allocating resources towards obtaining and implementing the required technology is essential. Similarly, the allocation of infrastructure resources, such as transportation and facilities, is crucial for the efficient functioning of the supply chain. Moreover, skilled professionals play an essential role in the implementation of a closed-loop supply chain. As noted by several authors, including Zhu et al. and Wu et al.[37], a team of skilled professionals is required to manage and optimize the various aspects of the supply chain. Thus, allocating resources towards hiring and training such professionals is equally important for ensuring the success of the closed-loop supply chain implementation.

5.3. Implementation timeline

Establishing a well-planned implementation timeline is crucial to the successful implementation of a closed-loop supply chain. It enables the project team to set realistic goals and objectives and allocate resources effectively. By identifying key milestones and deadlines for each stage of the process, the team can ensure that the project stays on track and that each task is completed on time. Regular progress monitoring helps to identify any issues that may arise and allows for adjustments to be made to the timeline as needed. In addition, an implementation timeline can also serve as a communication tool between stakeholders, keeping everyone informed about the progress of the project and ensuring that they are aware of upcoming milestones and deadlines. This can help to build trust and commitment among stakeholders and increase their engagement in the implementation process. Overall, developing a detailed implementation timeline is es-

Proceedings of M. F. E. G. I. M. - 2022/2023

sential to the success of a closed-loop supply chain implementation. It helps to ensure that the project is completed in a timely manner and that all stakeholders are aware of the progress and their roles and responsibilities throughout the process.

6. Figures

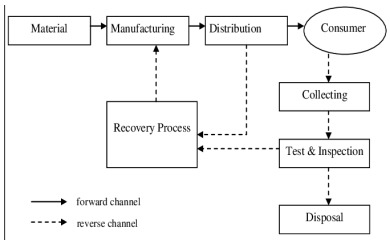


Figure 1



Figure 2

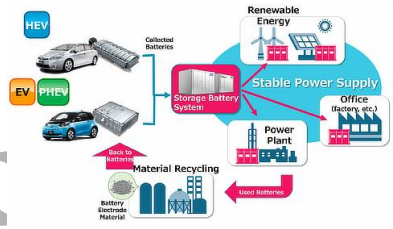


Figure 3

7. Conclusions

In conclusion, the adoption of closed-loop supply chain practices in the automotive industry has become increasingly important for companies seeking to improve their environmental performance, reduce costs, and enhance customer satisfaction. The state of the art review presented in this article has explored various perspectives and approaches proposed by scholars in this area. While these studies have shown that closed-loop supply chains can effectively improve economic and environmental performance, there is a need for further research to fully understand the impact of closed-loop supply chains on social and ethical factors.

To design a successful closed-loop supply chain, companies must consider key components such as reverse logistics, material recovery, remanufacturing, and design for remanufacturing. Additionally, it is crucial for companies to prioritize data quality and availability, as well as engage in collaborative efforts with stakeholders to ensure the sustainability and responsibility of their supply chains.

In summary, the findings from this state of the art review highlight the significant benefits of closed-loop supply chains in the automotive industry, while also identifying areas for improvement and further research. By incorporating key components into their supply chains, companies can achieve a more sustainable and responsible approach to business operations while also improving their economic performance.

Proceedings of M. F. B. G 1. - 2022/2023

Acknowledgements

I would like to express my sincere gratitude to my advisor,Mr.Agguini for his invaluable guidance and insightful suggestions in writing this article. I would also like to thank Mr.Boudhar for his exceptional teaching and support throughout my last three years of study.

References

[1] Colin Scott. Guide to supply chain management by colin scott. In *Guide to supply chain management*.

[2] David B. Grant and Alexander. Trautrims. Sustainable supply chain management: Practical ideas for moving towards best practice.

[3] Ming Liu, Jian Li, and Shuai Li. Closed-loop supply chain configuration for a sustainable auto industry. volume 10, page 2824. Multidisciplinary Digital Publishing Institute.

[4] Ahmad Alshamsi, Ali Diabat, and Kannan Govindan. A mixed integer programming model for closed-loop supply chain planning in the automotive industry. *Computers & Operations Research*, 74:95–110, 2016.

[5] Yan Wang, Lei Wang, Yong Shi, and Zhongkai Xiong. Multi-objective optimization model for

designing closed-loop supply chain networks in the automotive industry. *Journal of Cleaner Production*, 197:1–11, 2018.

[6] Fangxing You, Xiangwei Li, Ming Liu, and Lin Zhao. Decision support system for optimizing closed-loop supply chain of used electric vehicle batteries. *Applied Energy*, 238:239–251, 2019.

[7] Ana Carolina Marques, Marcelo Gomes Oliveira Filho, Luciano Antonio Gomes Gonçalves, and Suzana Pereira Santos. System dynamics model for the closed-loop supply chain of end-of-life tires in the automotive industry. *Journal of Cleaner Production*, 269:122235, 2020.

[8] Yiming Wei, Ling Zhou, Gong Cheng, Min Zhang, and Liang He. A multi-objective optimization model for designing closed-loop supply chains of lithium-ion batteries in electric vehicles. *Journal of Cleaner Production*, 277:124104, 2020.

[9] Tsan-Ming Choi, Christina Wai-Yin Wong, and Kee-Hung Lai. A closed-loop supply chain model for the remanufacturing of electric vehicle batteries: a sustainability perspective. *Journal of Cleaner Production*, 306:127254, 2021.

[10] Hua Su, Shuliang Wang, Jinxing Xie, and Di Fan. A closed-loop supply chain model for remanufacturing of automotive parts. *Journal of Cleaner Production*, 96:487–498, 2015.

[11] Tamer Abdallah and Ali Diabat. A multi-objective optimization model for designing a closed-loop supply chain in the automotive industry. *Computers & Industrial Engineering*, 98:317–327, 2016.

[12] Parvez Akhtar, Mohd Ali, and Mohammad Tahir Khan. Multi-objective optimization for designing sustainable closed-loop supply chain network for the automotive industry. *Resources, Conservation and Recycling*, 118:27–49, 2017.

[13] Winifred Ijomah, Christopher McMahon, Geoff Hammond, ST Newman, and Glenn Parry. A framework for the design and operation of remanufacturing networks in the automotive industry. *Journal of Remanufacturing*, 7(1):1–18, 2017.

[14] Shuai Jiang, Jiazhen Huo, Liangdong Sun, and Yong He. A closed-loop supply chain model for remanufacturing of automotive engines. *Journal of Cleaner Production*, 197:1355–1367, 2018.

[15] Ebru Akar, Mehmet Ali Ilgin, and Surendra M Gupta. A closed-loop supply chain model for remanufacturing of automotive batteries. *Journal of Cleaner Production*, 221:918–931, 2019.

[16] Michel Thierry, Marc Salomon, Jo van Nunen, and Luk van Wassenhove. Strategic issues in product recovery management. *California Management Review*, 37(2):114–135, 1995.

[17] Tanya Beaulieu and Shahjahan Sarker. Reverse logistics: a review of the literature and framework for future investigation. *Journal of Business Logistics*, 20(1):129–149, 1999.

[18] End-of-life vehicle (elv) recovery and recycling rates reported by eu member states. *ResearchGate*, pages 1–5, 2015.

[19] Erik Sundin and Bert Bras. Investigating the performance of disassembly systems through simulation: a case study. *Robotics and Computer-Integrated Manufacturing*, 21(1):17–27, 2005.

[20] Electrified vehicle battery reuse and recycling verification project. Technical report, 2021.

[21] Conrad Luttropp and Johan Lagerstedt. Ecodesign and the ten golden rules: generic advice for merging environmental aspects into product development. *Journal of Cleaner Production*, 14(15-16):1396–1408, 2006.

[22] Tzu-chi Kuo. *A disassembly model for end-of-life products recycling.* PhD thesis, Texas Tech University, 1997.

[23] Scott Coulter, Bert Bras, Galen Winslow, and Shannon Yester. Designing for material separation: lessons from automotive recycling. In *Proceedings of the 1996 ASME design engineering technical conferences and computers in engineering conference*, 1996.

[24] JAT Palmer. *Mechanical recycling of automotive composites for use as reinforcement in thermoset composites.* PhD thesis, University of Exeter, UK, 5 2009.

[25] Robert Hammond, Thomas Amezquita, and Bert Bras. Issues in the automotive parts remanufacturing industry: discussion of results from surveys performed among remanufacturers. *International Journal of Engineering Design and Automa-*

Proceedings of M. I. F. E. G. I. M. - 2022/2023

tion – Special Issue on Environmentally Conscious Design and Manufacturing, 4-1:27–46, 1998.

[26] BJ Jody and EJ Daniels. Automobile shredder residue: treatment options. *Hazardous Waste & Hazardous Materials*, 8(3):219–230, 1991.

[27] D. W. Pennington, J Potting, G Finnveden, E Lindeijer, O Jolliet, T Rydberg, G Rebitzer, J Gregory, MZ Hauschild, and R Heijungs. Life cycle assessment. part 2: Current impact assessment practice. *Environment international*, 30:721–739, 2004.

[28] Michael F Ashby. *Materials and the environment*. Butterworth-Heinemann, 2009.

[29] JJ Boon, JA Isaacs, and SM Gupta. Economic and environmental impact of aluminum-intensive vehicles: a life cycle perspective. *Journal of Industrial Ecology*, 10(1-2):139–160, 2006.

[30] Cornelia A Bulucea, Dan Alexandru Nicola, Liviu Sorin Lazarescu, and Andrei Stinga. Building awareness of sustainable automobile manufacturing within industrial ecology framework. In *Proceedings of the international conference on urban sustainability, cultural sustainability, green development green structures and clean cars*, pages 149–153, 2010.

[31] Markus A Reuter and Antoinette van Schaik. The effect of design on recycling rates for cars. Technical report, Delft University of Technology, Delft, the Netherlands, 2005.

[32] Thomas E Graedel and Braden R Allenby. *Industrial ecology and the automobile*. Prentice Hall International Ltd, 1994.

[33] Joseph Sarkis and Qinghua Zhu. Closed-loop supply chain management. *Encyclopedia of Sustainable Technologies*, 2:575–584, 2018.

[34] HJ Kim, SB Jun, and Y Kim. A stakeholder analysis of sustainable supply chain management in the automotive industry: The case of korea. *Journal of Cleaner Production*, 256:120404, 2020.

[35] Kannan Govindan, Mathiyazhagan Kaliyan, Devika Kannan, and A. Nabil Haq. Barriers analysis for green supply chain management implementation in indian industries using analytic hierarchy process. *International Journal of Production Economics*, 170:357–373, 2015.

[36] Mark Pagell, Zhaohui Wu, and Marc E Wasserman. Thinking differently about purchasing portfolios: An assessment of sustainable sourcing. *Journal of Supply Chain Management*, 46(1):41–55, 2010.

[37] Jun Wu, Jiazhen Huo, and Xiande Zhao. A review of green supply chain management in emerging economies. *Journal of Cleaner Production*, 123:42–55, 2016.

Proceedings of M. F. D. G. I. M. - 2022/2023