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Automating the Recycling Process in PLM: A Case Study from the Automotive Sector

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Abstract
The world is in the grip of a very hard challenge these last few years: the conservation of the environment. To reduce waste, we are initiating actions and recycling methods. Our study will focus on the automotive sector, which generates different types of waste, recyclable and non-recyclable. The article explores the innovative integration of product lifecycle management (PLM) from the beginning of life (BOL) to the end of life (EOL) stages, with the goal of creating a comprehensive recycling process. The automotive sector serves as a compelling case study to showcase the practical application of this holistic approach. The study illustrates how aligning BOL and EOL in PLM can lead to sustainable practices in the automotive industry. The results reveal a remarkable synergy between designing eco-friendly products, efficient manufacturing, and responsible disposal. The article emphasizes the significant environmental and economic benefits of optimizing the entire product lifecycle by connecting these stages. The article presents an automated model embedded within the PLM tool as a notable outcome, reflecting the combined process. The automated model embodies a futuristic vision that seamlessly integrates sustainable practices into product development and management, highlighting the immense potential for industries to contribute to a greener and more sustainable future.

Keywords
PLM, Recycling, BOL, EOF, Waste, Automation, Internet of Things (IoT) and Big Data.

Introduction

The world is experiencing a surge in waste production (Hogland and Stenis, 2000), which includes various types of industrial wastes such as construction wastes, special wastes, hazardous wastes, and storage wastes (Abduli, 1996). In order to properly treat these different types of waste, recycling methods prove to be the most suitable (Demirbas, 2011).

Recycling is a practice that consists of transforming an unwanted material into a new, desired product (Singh et al., 2014). Among the sectors that several countries consider that recycling is very important is the automotive sector, due to its impact on the environment as well as the rapid increase in their waste (Simic, 2013).

Recycling plays a crucial role in waste management across various industrial sectors, a task that humans have always performed (Bellmann and Khare, 2000). For this reason, having a decision-support tool for organizations will be very useful (Finnveden and Tomas, 1998). After the end of the life of a product, we must take into account a green manufacturing process to facilitate the management of waste (Vila et al., 2015).

To effectively manage recycling, a robust product life cycle management system is essential. Research reveals that Product Life Cycle Management (PLM) is a product management tool that facilitates collaboration among users (Yoga Mule, 2012). Therefore, the necessity of using such a tool stems from the traceability and information gathering of the product during its various life phases, including BOL, middle of life (MOL), and EOL (Cao et al., 2009). The PLM tool collects information throughout the product life cycle in order to analyze it and make decisions (Jun et al., 2007).

The PLM tool already considers the green product lifecycle (Vila et al. 2015). Furthermore, it's crucial to highlight that the Green 3R approach necessitates three key pillars: reducing energy and consumption, recycling elements at the end of their lives, and reusing elements after treatment or evaluation (Rahman and Mashud, 2015). comprehensive recycling and waste disposal system (Kundaragi et al., 2023). It's crucial

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to understand that at the end of a product's life cycle, recycling separates residues into recycled goods and waste, and then processes these recycled goods for reuse in production systems (Fuse and Shigeru 2008).

Having an intelligent system that allows us to control waste will be very beneficial; therefore, it is called smart waste (Shyam et al., 2017). This system provides a variety of recycling options, allowing us to understand the breakdown of these materials and explore their potential for reuse (Shukla and Hait, 2022). One system, the PLM tool, adheres to a green product lifecycle management (PLM) policy (Vila et al. 2015). However, PLM does not support recycling, disposal, or reuse in its tool (Diakun and Dostatni 2020). In addition, recycling, collection, and reuse of vehicles are still on the agenda as a very important topic in order to develop a comprehensive approach to waste management (Lu et al., 2014).

We conducted a survey and held meetings with the PLM leaders to implement modifications to the PLM process, including vehicle recycling management. The results showed that 66.67% of respondents indicated that the tool does not handle this aspect.

The purpose of this article is to seamlessly integrate recycling management in the automotive sector into the PLM tool, thus improving communication throughout a product's lifecycle. By demonstrating the importance of this integration and its impact on the efficiency of recycling processes, the article aims to highlight the need to establish effective communication between the different phases of a product. In addition, the article seeks to automate recycling management, thus streamlining the entire process. To achieve these objectives, the article presents a comprehensive plan that includes verifying the relevance of the approach through a case study, illustrating the communication flow within PLM between the beginning-of-life (BOF) and end-of-life (EOL) stages, connecting the vehicle recycling process to the PLM tool, and building a recycling process model within the PLM tool to facilitate seamless integration between BOL and EOL.

Methodology

We aim to incorporate recycling into the Product Lifecycle Management tool. Our methodology will highlight the importance of this integration, improve communication throughout a product's life cycle, emphasizing the criticality of inter-phase communication, and ultimately automate the recycling management process. To achieve this objective, we will proceed according to the following plan:

- Verify the relevance of our problem in the case of a car manufacturer.
- Illustrate the communication between the beginning of life (BOF) and the end of life (EOF) in the PLM.
- The PLM tool should be connected to the vehicle recycling process.
- In the PLM tool, create a model of the recycling process: Ensure effective communication between BOL and EOL, and create a design that will simplify the integration process within the PLM tool.

The relevance of our problem through the case of a car manufacturer

This case explores the efforts of a leading car manufacturer to reduce the amount of waste going to recycling, outlining the challenges faced, strategies implemented, and outcomes achieved.

The car manufacturer in question is a global brand that produces a wide range of vehicles. The company has a long-standing commitment to sustainability and reducing its environmental impact. However, it recognized that there was still significant room for improvement in its waste management practices.

Due to a lack of traceability, the only data that contains the number of wastes by department is for the years 2016, 2017 and 2022. We have not included the data for the years 2018, 2019, 2020, and 2021 due to the absence of actual data (Fig. 1).

Following this sample, we noticed that the assembly, sheet metal work, and factory contain the most waste. The waste from the factory includes waste from sheet metal work and assembly, so we decided to assign all waste that does not enter the automobile manufacture category to the factory category.

After brainstorming in collaboration with the environmental managers, the following non-conformities were detected:

- The traceability of the data is not documented
- Process not digitized.
- Waste sorting is not reliable.

Our manufacturer incorporates the green concept into all these areas. However, with factories transitioning to Industry 4.0 and PLM being a key component, we have chosen to model a vehicle recycling management system to foster communication among all stakeholders.

Before building communication between stakeholders, it is necessary to identify the importance of communication between the phases of PLM by involving recycling management.

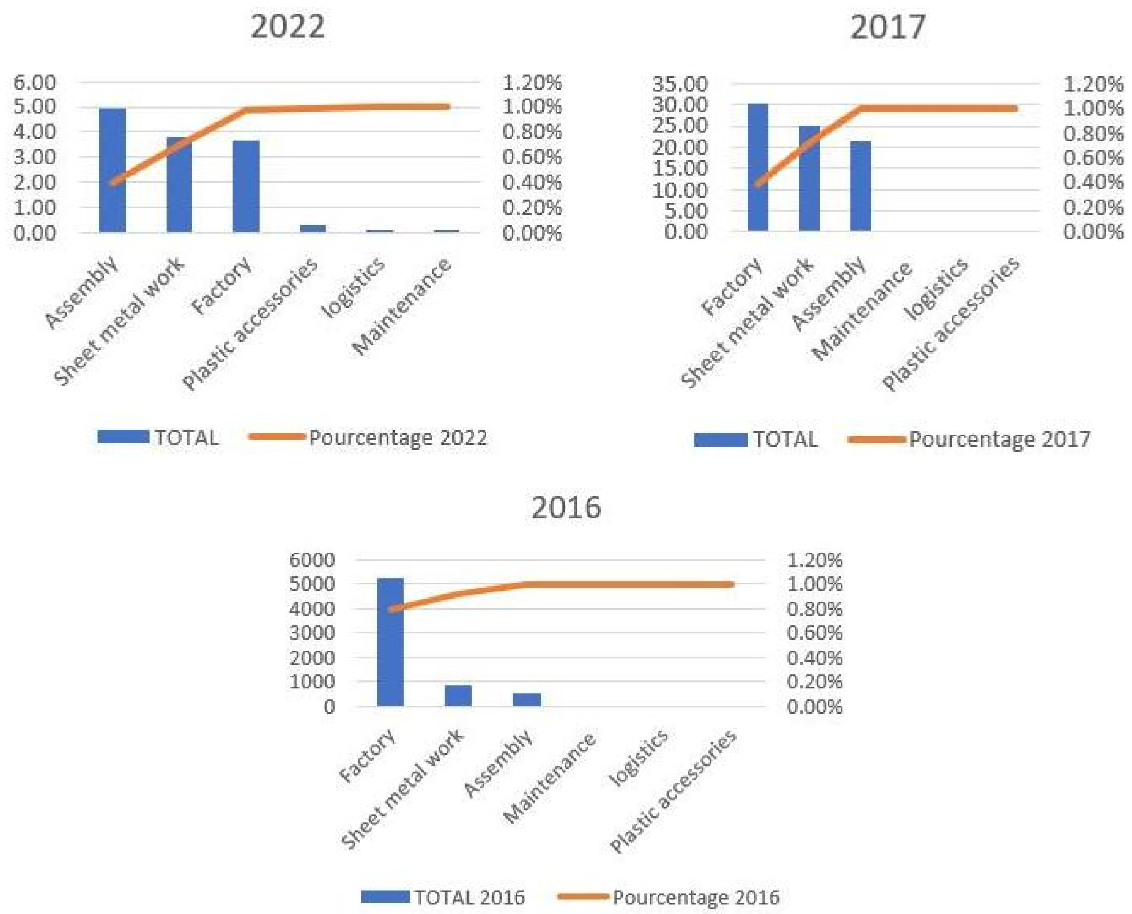


Fig. 1. Waste by department. 2016, 2017 and 2022

The communication between Beginning of Life (BOF) and End of Life (EOF) in the PLM

To highlight the communication between the PLM phases, we based our modification on the model of PLM established by (Terzi et al. 2010) to show the objective of our recycling management.

In fact, the model proposed by (Terzi et al. 2010) illustrates the methods and tools used throughout the PLM; however, it does not address beyond EOF, i.e. recycling, and how we will have communication between BOF, MOF, and EOF. That's where our idea originated. Observing its model gave us the idea to go beyond the EOF by creating a recycling management system and establishing communication between the BOF and the EOF.

This model (Fig. 2) represents the communication between BOF and EOF, the feeding of the knowledge base, and the continuous improvement of the recycling rate.

From BOF, estimate the recycling rate for both the by-product and the final product. Then, transfer this data to EOF for a comparison of the recycling rate once the product reaches its end of life. This action will enable us to improve the KPIs (Key Performance Indicators) and incorporate them into the new product.

To take into account and manage the waste in factories by following the recycling process

Finally, the recycling management in the EOF will enable the creation of a catalogue containing reusable parts for resale, thereby reducing costs for the manufacturer. This communication will enable effective management of the recycling process for both products and vehicles. Generate a recycling report for the environment department to ensure traceability and follow-up on the process.

The model below takes recycling management into account; our case study is in the automotive sector, and it is critical to develop a recycling process that is compatible with our PLM tool (Fig. 2).

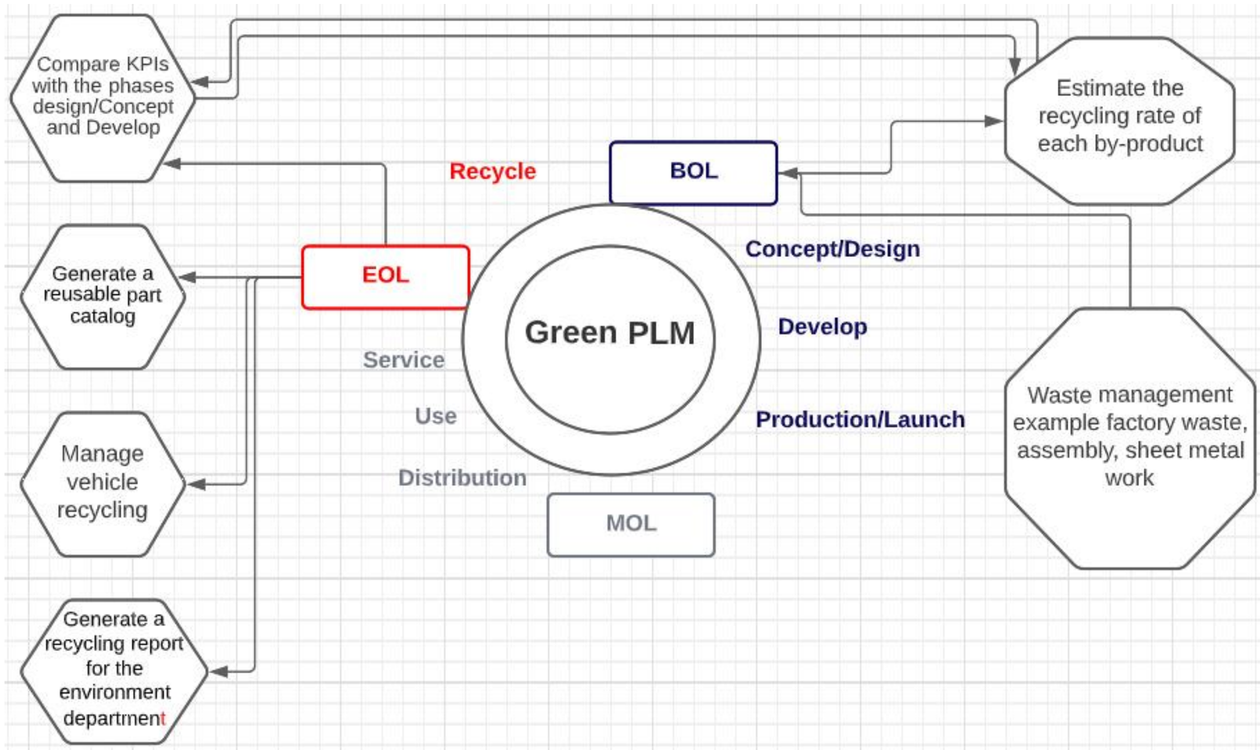


Fig. 2. A recycling management model is included in the PLM tool

The vehicle recycling process can be connected to the PLM tool

Prior to implementing this management strategy, it is crucial to first conceptualize the car recycling process. We have been inspired by the phases of recycling proposed by (Wang et al. 2005, Hiratsuka et al., 2014). Their model solely focuses on the recycling phases without any connection to the Process Life Model (PLM). Our model, on the other hand, proposes to incorporate production waste into the recycling process and integrate it with the PLM tool.

Prior to modeling the process in Fig. 3 in the PLM tool, we must first demonstrate the communication we have established between the recycling process and the PLM tool. This table shows the notes proposed in Figure 3, which illustrates the link between the recycling process and the PLM tool.

This communication can be seen in Table 1, which will allow us to automate it in the PLM tool.

How recycling processes are integrated in current PLM systems:

- The PLM tool collects product data from the beginning of life (BOF), such as material types and components. To integrate recycling, the tool must also gather information on the recyclability of these materials, available recycling streams, and environmental regulations. This is why Figure 2 highlights the importance of establishing communication between the beginning of life (BOF) and end of life (EOL) to compare data collected at different stages of the process.
- PLM tools can evaluate the recyclability of product designs by estimating the recycling rates of the by-product and final product at the beginning of life (BOF), then transferring this data to the end of life (EOL) to compare the recycling rates after the product has reached its end of life.
- Every improvement in the recycling rate will allow for product design optimization, making them easier to disassemble and recycle at the end of their useful lives.
- PLM systems often integrate supply chain management modules that track the origin of materials and ensure compliance with environmental standards throughout the manufacturing process.

Among the weaknesses that can be identified:

- Environmental regulations vary from country to country, complicating regulatory compliance management in international PLM systems.
- There is a significant effort required to obtain precise data on the recyclability of materials and components.

Table 1
Notes on the car recycling process

Notes	Comments
Note 1	Insert in the PLM tool the Vehicle recovered for recycling as well as the waste from the production of the factory
Note 2	Insert the type of fluid to be drained (oil, antifreeze, brake and transmission fluids, and various lubricants), name of the stock, and processing destination
Note 3	Order the reusable parts, reference them, mentioning: name of the part, origin of the part, quantity to be stored, age of the part, selling price, name of the final stock. In this phase we can generate the catalog of used car parts
Note 4	The parts that cannot be reused and resold. In the system we add the reference, name of the part, quantity, name of the stock, type of danger and destination of the part
Note 5	In this phase we proceed to the grinding. In the system we introduce, the reference of the carcass, model, number of the mill, stock.
Note 6	After the crushing phase, the metals must be separated into ferrous and non-ferrous materials. Type of remaining residues (Glass, plastic...). Destination of these materials
Note 7	The rest of the melted scrap, add the reference, Type of material, stock and destination

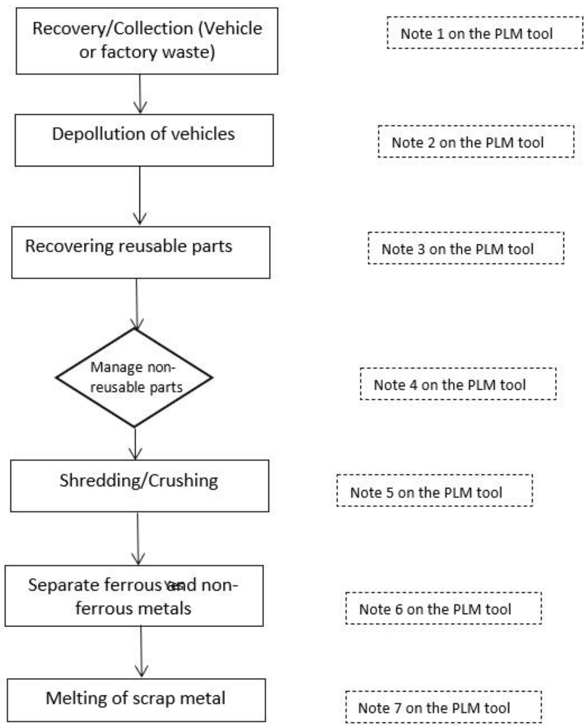


Fig. 3. Vehicle recycling process

Classification of the vehicle manufacturer's waste according to the recycling process

Following the recycling process, the waste was sorted according to the process to facilitate the transfer of data to the department / recycling company. As a result, this preliminary data management tool will enable the stakeholder to track the data, ensure traceability, and calculate the recycling rate (Fig. 4).

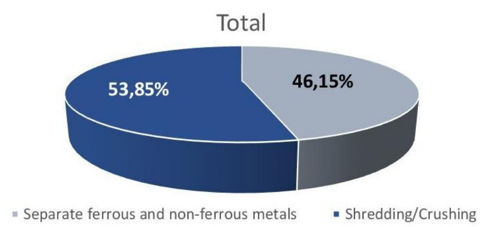


Fig. 4. The recycling process distributes waste

A breakdown of the waste of the year 2022 and made following Figure 3, which positions at the stage "Manage Factory waste" (BOL), data will be inserted in management tool and transfer directly to the EOF phase of the PLM tool in order to process them, which will allow to have a traceability of data, to calculate the recycling rate, to improve the recycling rate of each sub.

Modeling/automation of the recycling process in the PLM tool

The ultimate objective is to automate the recycling process while considering the two models presented in Figures 2 and 3. The proposed model below utilizes digital modeling within the PLM tool to effectively manage recycling and achieve our objective.

The UML class diagram was chosen to model process, because it is the most appropriate, allowing for a conceptual and detailed modeling of the system structure.

The decision to choose UML over Merise MCD was made because UML is a more advanced model for complex systems, allowing for code generation on tools commonly used by the automotive industry, and it is also the most widely used in this sector.

The PLM tool models the communication between BOL and EOL

Models were verified and validated by a consulting firm that specializes in digital transformation.

The creation of communication between BOL and EOL will allow the PLM tool to compare the results obtained in EOL so that the design and modeling teams can adjust their data (Fig. 5).

Through the automation of Figure 6, we will have communication with the different stakeholders, namely: This communication will allow for good management of recycling, optimization of waste within production, a history of waste, and a gain in cost following the sale of reusable parts.

Figure 7 presents a model of a recycling management solution that integrates into PLM, highlighting the connections between BOL and EOL to enhance the knowledge base. This knowledge base may consist of text documents, databases, process models, metrics, and data relating to product design processes and the recycling rate of their components, with the aim of improving this process and optimizing its recycling rate. Professionals use it to make decisions, solve problems, and carry out specific tasks.

Our developed design has certain features or capabilities that make it easy for developers to integrate the PLM tool with other systems or applications. It can also be useful to PLM managers, who are responsible for managing product lifecycles. This could be because the design helps streamline workflows or provides better information about product data.

Overall, if our design is executed well and addresses the key pain points in the integration process, it can be very useful for a wide range of users.

BOL in PLM tool:

Fig. 5. Recycling process diagram class BOL

EOL in PLM tool:

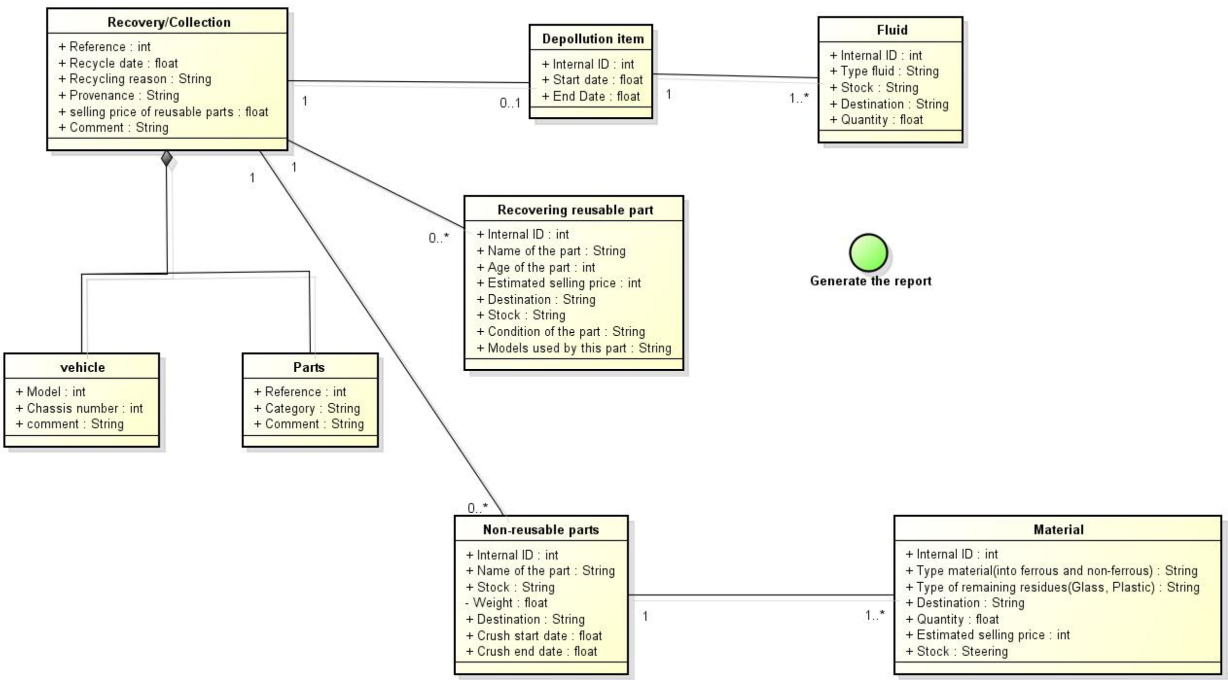
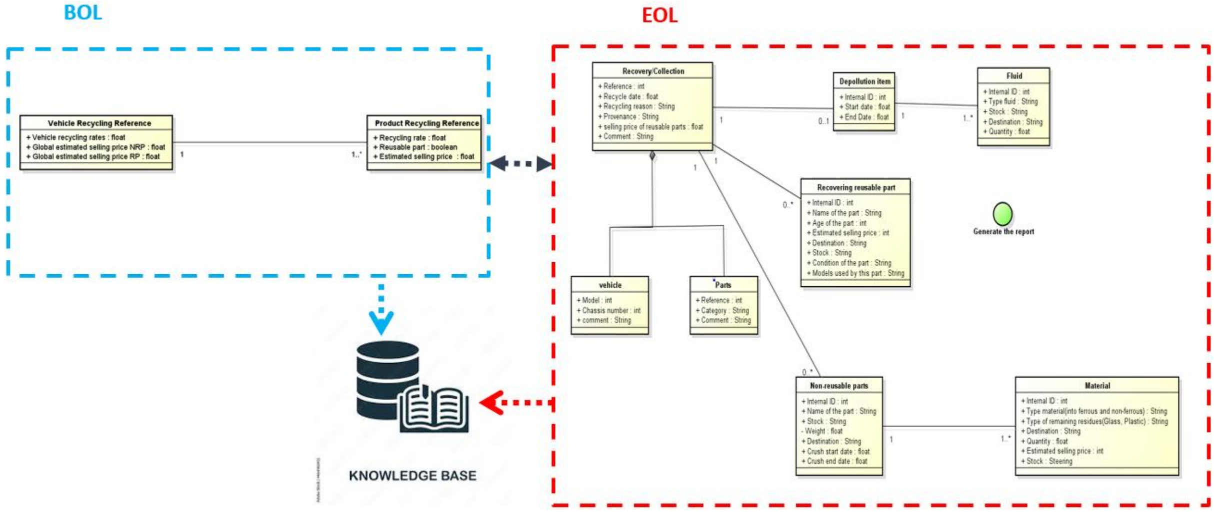


Fig. 6. Recycling process diagram class EOL

EOL in PLM tool:



←···→: BOL and EOL communication.
······→: The EOL phase boosts the knowledge base.
······→: The BOL phase boosts the knowledge base.

Fig. 7. Communication between the two phases

Recycling in PLM 4.0

In recent years, Industry 4.0 has gained prominence as the prevailing term in the manufacturing sector (D'Antonio et al., 2017). When implementing Industry 4.0, it becomes evident that the Internet of Things (IoT) and big data play pivotal roles in reconfiguring processes, methodologies, and services... (Sestino et al., 2020). PLM plays a crucial role in Industry 4.0, connecting IoT, automation, and data analysis. It enables seamless integration and data-driven product management in the contemporary industrial landscape, thereby optimizing product development and lifecycle management in the Industry 4.0 era (Kundaragi et al., 2023). Experts see the deployment of IoT and Big Data as a strategy to enhance people's daily lives and surroundings through smart services and processes (Malek et al., 2017).

Automation of recycling processes has garnered significant attention from researchers (Li et al., 2019). As extensive research continues to focus on preserving our planets finite resources, the significance of intelligent recycling becomes increasingly evident (Ziouzios and Dasygenis 2019).

Figure 2 illustrates how our UML-based recycling model is seamlessly integrated into our smart recycling system. Within this system, PLM harnesses the power of artificial intelligence to precisely estimate recycling rates and assess the value of recyclable materials. Furthermore, it allows us to dynamically calculate the price of reusable automotive parts, making our recycling process highly efficient, resource-conscious, and smart.

Based on the models proposed by (Goto et al., 2016) and (Li et al. 2015), we have created this model below to illustrate the communication between BOL and IOL for vehicle recycling in I4.0 (Fig. 8).

The provided figure visually depicts an essential aspect of product lifecycle management (PLM) – the interaction between the Beginning of Life (BOL) and End of Life (EOL) phases, which is crucial for the efficient management of vehicle recycling within the PLM tool. This illustration showcases how the Internet of Things (IoT) and big data significantly contribute to the seamless coordination of these lifecycle stages. In the context of Industry 4.0, characterized by advanced automation and connectivity, the amalgamation of IoT and Big Data capabilities holds substantial promise, particularly within the automotive sector. This synergy empowers the PLM tool to optimize recycling processes, enhancing resource utilization and sustainability, which are paramount in the industry 4.0 landscape.

The role of the IoT platform, otherwise known as the internet of everything or the internet, is to facilitate the connectivity and management of intelligent devices, collecting data in real time for analysis and use in a variety of applications to automate and optimize processes (Lee and Kyoochun, 2015). The massive volumes of data generated by the IoT are processed by Big Data, which analyzes and transforms them into meaningful information, creating a powerful tech-

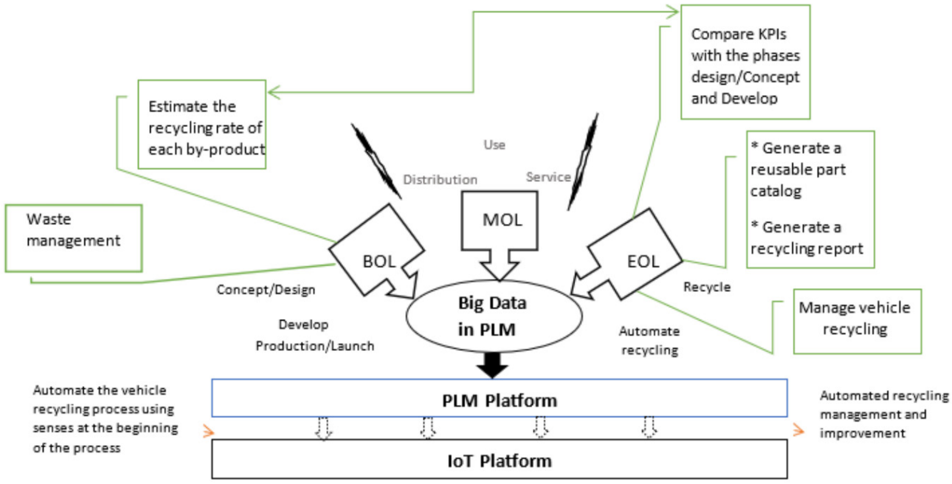


Fig. 8. Recycling in PLM 4.0

nological ecosystem (Li et al., 2015). By combining PLM and IoT, we can correlate real-world product performance data with virtual design analysis. This alignment between practical use and initial design evaluations enhances products and lowers costs for future iterations (Goto et al., 2016). Therefore, leveraging "Big Data" methodologies allows for addressing product-related issues and facilitating decision-making by analyzing vast datasets across various stages: beginning of life (BOL), Middle of life (MOL), and end of life (EOL) (Li et al. 2015).

The preceeding paragraph elaborates on our model's primary focus, which is to establish a robust connection between PLM and PLM 4.0, thereby facilitating seamless communication across various phases of a vehicle's lifecycle, particularly the end-of-life recycling phase.

This integration relays real-time data and insights generated during the recycling process to the Beginning of Life (BOL) stage for thorough processing, analysis, and enhancement of recycling efficiency. It also allows for modifications to be made to future vehicles' design and functionality based on the knowledge gained. Another integral facet of our model is the automation of the recycling process, streamlining it for effective archiving and dissemination of pertinent information to all stakeholders involved. This comprehensive approach aids in fostering sustainability and resource optimization throughout the entire product lifecycle.

Discussion

This article represents a significant step forward in constructing a recycling model that is seamlessly integrated into the existing PLM tool infrastructure. This model, elegantly depicted through a class diagram, establishes a crucial link between vehicle recycling processes and the PLM tool, thereby creating a unified and efficient system. By facilitating communication between the beginning-of-life (BOF) and end-of-life (EOL) stages within the PLM tool, we have not only illustrated but also operationalized the flow of communication. This innovative model signifies a significant achievement, enabling organizations to holistically manage the entire lifecycle of their products, ensuring a comprehensive approach from initial design to end-of-life responsible processes. Looking ahead, future research opportunities include the development of software designed to seamlessly integrate our recycling class diagram model into the PLM tool. This software would serve as a powerful bridge, enabling organizations to transition towards a circular economy by effectively managing the lifecycle of their products, from conception and production to end-of-life processes.

Conclusions

The world has begun to adopt a more environmentally conscious mindset, leading many organizations to strive for waste optimization. Recycling is one of the most popular methods, and our article focuses on digitalizing recycling management in the automotive sector using the PLM tool. To do this, it was essential to improve and create a PLM process model by adding the recycling management part, which integrates communication between BOF and EOF, and then come up with a recycling process in the PLM tool to finally model/digitize this process in the PLM tool. The article's case study highlights the significance of considering the recycling process from BOF, exemplified by effective data traceability for EOF use, efficient recycling management, and the digitization of the recycling process within the organization.

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