Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF6.20250220
Published: April 8, 2025

The Effective Integration of Smart Technologies to Facilitate Reverse Logistics Management

Faycal MIMOUNI
Laboratory of Advanced Systems Engineering (ISA)
ENSA & EST, Ibn Tofail University
Kenitra, Morocco
mimounifaycal@gmail.com

Ossama AOUANE
LAMSO
ENCG Casablanca Université Hassan II
Casablanca, Morocco
ossama.aouane@gmail.com

Rabiî EL GOMRI
ISTL
Institut Supérieur de Transport et de la Logistique
Casablanca, Morocco
gomri.r@gmail.com

Driss SERROU
Laboratory of Advanced Systems Engineering (ISA)
ENSA & EST, Ibn Tofail University
Kenitra, Morocco
d.serrou@gmail.com

Abstract

The increasing development of smart technologies is revolutionizing the supply chain by improving efficiency, visibility, and decision-making. Thus, these smart technologies would, if implemented in Reverse logistics, which involves the handling of returned, reused, or recycled products, significantly reduce the challenges related to cost, coordination, and sustainability to improve efficiency. In order to evaluate the efficiency and the impact of these new integrations, our study will employ simulation model to assess the impact of smart technologies by comparing a classical reverse logistics supply chain with no smart technologies integration and then multiple scenarios with each we integrate a new different smart technology and then one final scenarios where we will implement the maximum of smart technologies. Through these simulations, we analyze how these implementations can improve key performance indicators, including cost reduction, processing speed, and environmental sustainability. By comparing different integration strategies, this research identifies the most effective configurations for leveraging smart technologies in reverse logistics.

The findings highlight the potential benefits of these innovations, offering insights for businesses seeking to enhance their sustainability efforts while improving operational performance. This study contributes to the growing body of knowledge on digital transformation in supply chain management and supports the development of data-driven strategies for circular economic initiatives.

Keywords
Reverse logistics, Industry 4.0, Simulation, system modeling.

1. Introduction
In these last years, the Moroccan automotive industry has become a key driver of economic growth with major global manufacturers such as Renault, Stellantis, and numerous suppliers establishing more and more operations in Morocco. The sector has experienced significant expansion due also to the logistic hub and the proximity to the European market. However, the more vehicle production increases, so does the return thus increasing the challenge of managing reverse logistics—the process of handling returns, recycling parts, and ensuring the proper disposal or refurbishment of automotive components. The main challenge faced in the reverse logistics is the uncontrollable and unpredictable of returned products hence the difficulty of having a precise forecast system in order to plan the return logistics. Also, when collecting the returned products, we have different option to how to integrate the returns into the production process.

RLs adoption can help minimize the adverse environmental impacts through recycling and reusing end-of-life products. Other than that, it can have immense economic and social benefits as well (Shahparvari et al. 2021).
It has become common knowledge that the arising digital technologies could improve the efficiency of the operations of supply chains (SCs) worldwide (Govindan et al. 2018; Dubey et al. 2019). Both academia and practitioners have widely reported the potential benefits of the integration of digital technologies and SC management (Kamble et al., 2020b). Implementing these novel technologies can help SCs to perform more efficiently (Chiappetta Jabbour et al. 2020). The operations and SC management could be restructured through Industry 4.0 (I4.0), named after the 4th industrial revolution. The name refers to the prevailing trend of exchange of data and automation in manufacturing technologies, like the Internet of Things (IoT), cyber-physical systems, and cloud computing, which could lead to forming smart factories (Govindan et al. 2018; Koot et al. 2021).

Industry 4.0 can offer insightful directions to promote the circular economy and RLs (Dantas et al. 2021). The technologies have the potential to be used in different operations of the RLs, like disassembly, recycling, recovery, and remanufacturing (Chiappetta Jabbour et al. 2020). I4.0 initiatives such as sensor-based infrastructure and big data can further boost efficiencies of product tracking, demand forecasting, and responsiveness of the RLs (Manavalan and Jayakrishna 2019). Hence, there could be good opportunities for companies looking for a higher sustainable profile through the adaption of I4.0 technologies on their RLs.

This study aims to examine the integration of smart technologies in reverse logistics processes, using Morocco as a case study to highlight both the opportunities and challenges in an emerging economy. And thus, will be organized as follows. First, our literature review will be presented on two sections. The first one will present the various studies treating reverse logistics. And the second one will be presenting a detailed literature of reverse logistics in industry. Then, we will put the light on our methodological approach to modeling and simulation of the different scenarios of reverse logistics implementations. In order to study the impact oof new technologies on reverse logistics, we will test different scenarios using a case study and then discuss the obtained. We will then conclude our article with a conclusion and work perspectives

1.1 Objectives
The objective of our research is to study the effectiveness of integration of smart technologies to facilitate reverse logistics management by using simulation to compare between different scenarios by implementing different new technologies. The objective is to measure the effectiveness of these new technologies on the reverse logistics

2. Literature Review

2.1 Reverse Logistics: Definition and Importance

The term reverse logistics is the most commonly encountered in the literature when discussing returns management and the processing of recovered products. This term reflects the idea that logistics activities are carried out in the opposite direction compared to the regular supply chain operations. Given the growing interest in reverse logistics over the past decade, it is not surprising that the terminology surrounding it remains varied and somewhat inconsistent. In academic literature, reverse logistics is often examined within specific contexts. It may focus on activities such as product disassembly in electronic commerce or be studied through case analyses of particular types of returns. For instance, Thierry et al. (1995) refer to reverse logistics as Product Recovery Management (PRM), defining it as:

"The management of products, components, and materials used or disposed of that are the responsibility of the manufacturing company. The objective of product recovery management is to obtain the maximum economic and environmental value reasonably possible while minimizing waste."

Similarly, Beaulieu et al. (1999) and Beaulieu (2000) describe reverse logistics as:

"A set of management activities aimed at reintegrating non-core assets into sectors with added value."
More recently, reverse logistics has been closely associated with the concept of the Closed-Loop Supply Chain (CLSC) (Ramezani et al. 2014; Govindan et al., 2015), which focuses on managing the recycling and recovery of end-of-life products (Guide & Van Wassenhove 2009; Das & Posinasetti 2015). A CLSC generally involves manufacturers overseeing the reverse logistics process, either by directly recovering returned goods or through intermediary channels (Ashayeri et al. 2015). These returned goods are then resold in primary or secondary markets after appropriate processing (Turrisi et al. 2013).

Essentially, a CLSC extends the traditional forward supply chain by incorporating reverse logistics activities such as product returns, recycling, recovery, remanufacturing, and resale (He 2015). Over the past decade, CLSC has emerged as a major focus in supply chain management literature, with increasing attention devoted to understanding, optimizing, and improving this structure (Adenso-Díaz et al. 2012; He, 2015).

In recent years, the integration of advanced technologies has significantly transformed reverse logistics and closed-loop supply chains (CLSCs). Artificial intelligence (AI) and machine learning (ML) are now employed to analyze return patterns, enabling businesses to predict and manage returns more effectively. Automation has expedited the sorting and processing of returned items, reducing errors and enhancing efficiency. The Internet of Things (IoT) facilitates real-time tracking of returned products, providing greater visibility and control over the reverse logistics process. Additionally, blockchain technology ensures secure and transparent transactions, fostering trust among stakeholders. Augmented reality (AR) is also being utilized to improve warehouse operations by providing real-time information to workers, thereby increasing productivity and accuracy. These technological advancements not only streamline operations but also contribute to sustainability efforts by promoting recycling and reducing waste.

2.2 Smart Technologies in Reverse Logistics

Previous studies have focused on the underlying design principles of Industry 4.0 to achieve a circular economy (CE) by increasing production capability and improving product quality at an optimal cost (Abdul-Hamid et al., 2020). Lieder and Rashid (2016) emphasized the advantages of CE, including reduced environmental deterioration and increased social, economic, and sustainability benefits by incorporating the three Rs—reduce, reuse, and recycle—into the supply chain.

However, prior studies have also argued that CE has struggled to integrate with technological advancements necessary to effectively implement the 3Rs for sustainable production and consumption. For instance, Heyes et al. (2018) and Kinnunen & Kaksonen (2019) highlighted that technological advancements in CE remain relatively low, limiting the ability to recover resources and energy efficiently. On the other hand, Gigli, Landi, and Germani (2019) contended that, in the era of IoT advancements, leveraging technological capabilities can generate economic benefits for manufacturing firms while enhancing supply chain sustainability.

This study is crucial in bridging these gaps, as Industry 4.0 could facilitate the implementation of the 3Rs in manufacturing processes. According to de Sousa Jabbour et al. (2018), advanced manufacturing technologies have the potential to enhance circularity within the supply chain. Disruptive technologies based on Industry 4.0 principles have now addressed many CE challenges, offering real-time information, tracking resource flow, monitoring parts/components, and improving performance. However, the connection between Industry 4.0 and CE remains only partially explored, as manufacturing industries are often reluctant to adopt Industry 4.0 due to high costs, lack of information, and a shortage of ubiquitous technologies for cleaner production (Su et al. 2013).

Industry 4.0 has the potential to pave the way for CE by tracking products post-consumption to facilitate remanufacturing and refurbishment. Since the technological benefits of Industry 4.0 remain underexplored, this has been identified as a significant research gap. Nevertheless, manufacturing industries are increasingly adopting advanced technologies that enable human-machine interaction on the shop floor and facilitate seamless communication between the cyber and physical worlds. Horváth and Szabó (2019) examined key elements of Industry 4.0 and CE to develop business models that focus on remanufacturing and recycling waste products. Similarly, Wang et al. (2017) demonstrated that reused products can function as new ones, with customer purchasing behavior remaining unchanged even without green incentives.

Their study further indicated that remanufactured components serve as effective substitutes for newly manufactured products.Although some researchers have analyzed the relationship between reverse logistics (RL) and Industry 4.0, these two concepts have largely been studied separately from different perspectives. An integrated CE-RL network within Industry 4.0 could serve as a decision-making platform for enhancing resource circularity in supply chains. Additionally, it would create value from discarded products and waste through remanufacturing and refurbishment processes. Thus, product returns play a crucial role in enabling manufacturing industries to design and maintain sustainable operations.

3. Methods

Our objective in this study is to measure the effectiveness of integrating new technologies in reverse logistics in order to facilitate the reintegration of returned products into the production process. The main challenges that we face in reverse logistics in comparison to the standard supply chain are:

Table 1. Differences between traditional logistics and reverse logistics

Aspects	Traditional Logistics	Reverse logistics
Prediction	Relatively simple	More difficult
Product packaging	One to many	Many to one
Destination/ route	Uniform	Non uniform
Options available	Uniform	Non uniform
Price	Defined	Indefinite
Importance of speed	Clear	Undefined
Layout	Relatively uniform	Depending on several factors
Distribution cost	Recognized	Not considered a priority
Inventory management	Easily identifiable	Less readily identifiable
Life cycle of product	Consistency	Inconsistency
Negotiation	Easy to manage	More complex to manage
Marketing methods	Directly between the parties	Complicated
Visibility of the process	Although known	Complicated by several factors
Product packaging	More transparent	Less transparent

In order to face those challenges, we see new technologies as a way to automate the integration of reverse logistics with minimal perturbations on the supply chain. In order to measure the effectiveness of this integration, we propose

use simulation of different scenarios to evaluate the impact of new technologies in reverse logistics and on the global process.
In order to diagnostic the effectiveness of the integration of new technologies on reverse logistics, we will study their impact via simulation. The studied industry will be characterized as follows:

- Industry comprises producing a product from different components.
- The production of the product is continuous unless the stock is loaded.
- Supply of raw materials if the stock level falls to 10% of maximum stock.

In reverse logistics, the enterprise collects returned products from clients and sorts them based on the necessary treatments to maximize their value:

- Different levels of reparation to restore the product.
- Dismantling the product to collect components.
- Salvage to collect raw materials.
- Disposing of the product.

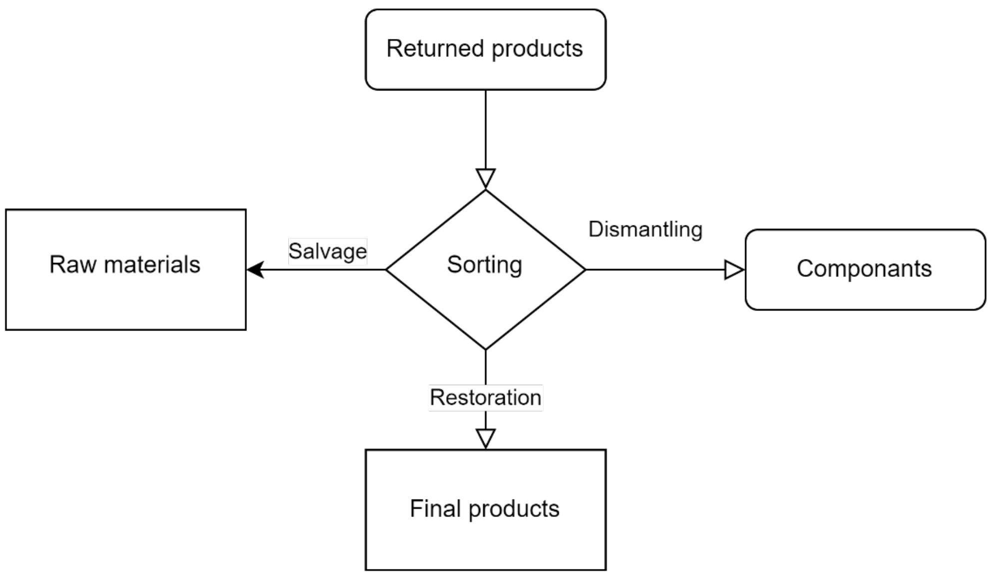

Figure 1. Returned products treatment

The input date for all simulation models will be the same and pushed by the clients demands with return based on random distributions based on historical data to simulate the randomness of reverse logistics.

In order to study the impact of smart technologies on reverse logistics, we propose different scenarios for the same company in the automotive sector:

- Classic reverse logistics;
- Reverse logistics with AI-powered image recognition to classify returned items on their way to the company;
- Reverse logistics with additive manufacturing (3D printing).

The objective is to compare the results obtained from these 4 scenarios and study the impact of each smart technology on the reverse chain logistics.

<u>**Key Factors for comparison:**</u>

- <u>Time needed for returned products</u>
- <u>Cost of reverse logistics</u>
- <u>Recovered value</u>
- <u>Net gain</u>

Scenario 1: Classic reverse logistic

In this scenario, we will simulate the classical reverse logistic:
Our source of returned products will be the collect mainly after client's demand. Once the products reach the company, there will be a manual sorting operation in order to identify the sate of each collected products. The different possible treatments are as follow:

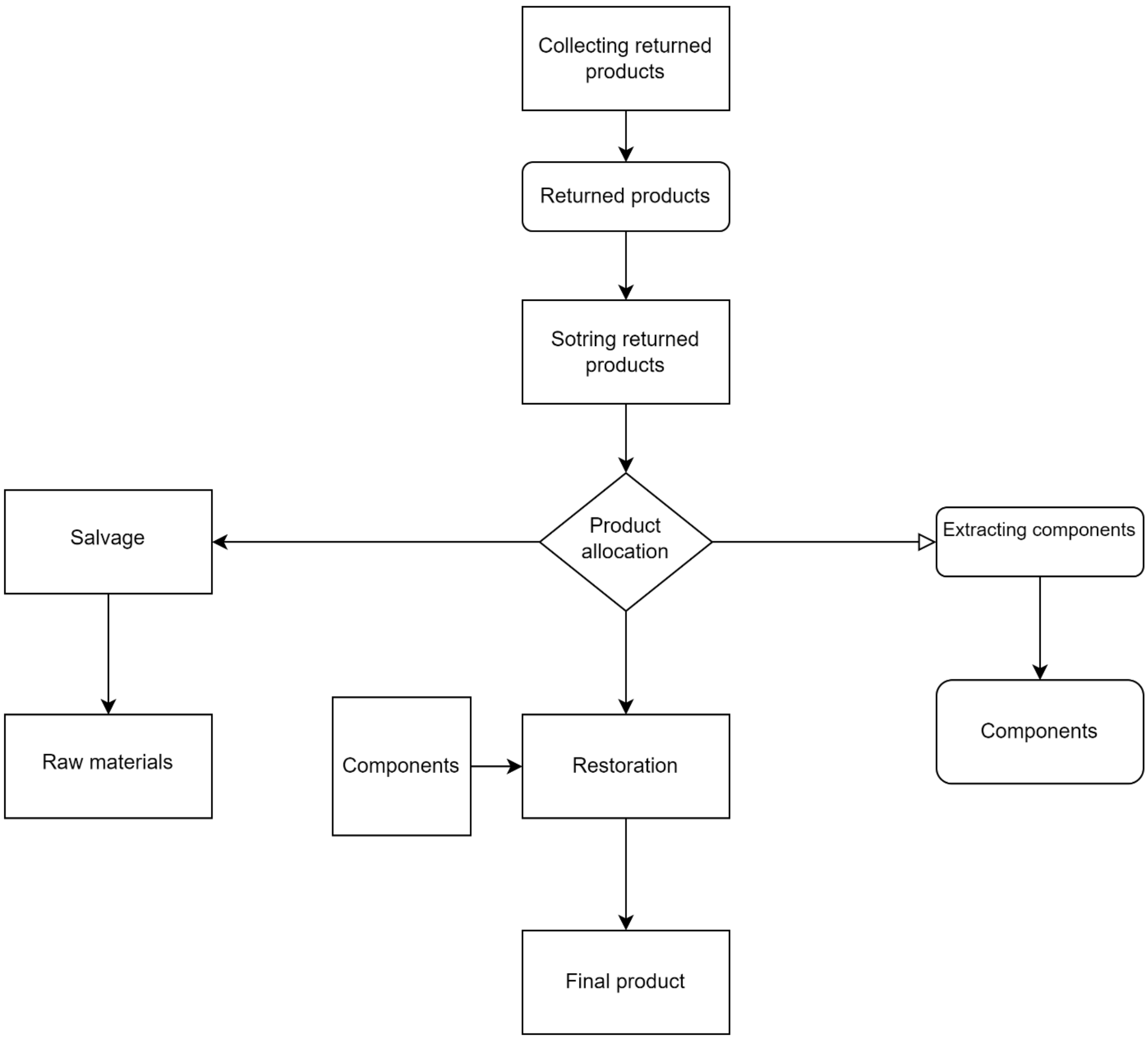

Figure 2. First scenario model

The first scenario will be used as base of comparison to study the impact of new technologies.

Scenario 2: Reverse logistics with AI-powered image recognition to classify returned items on their way to the company;

In order to gain time in the sorting process, we propose to implement an AI-powered image recognition to classify returned items on their way to the company. Once the product is collected, its picture will be sent and analyzed to identify the needed treatment. The process will be as follow:

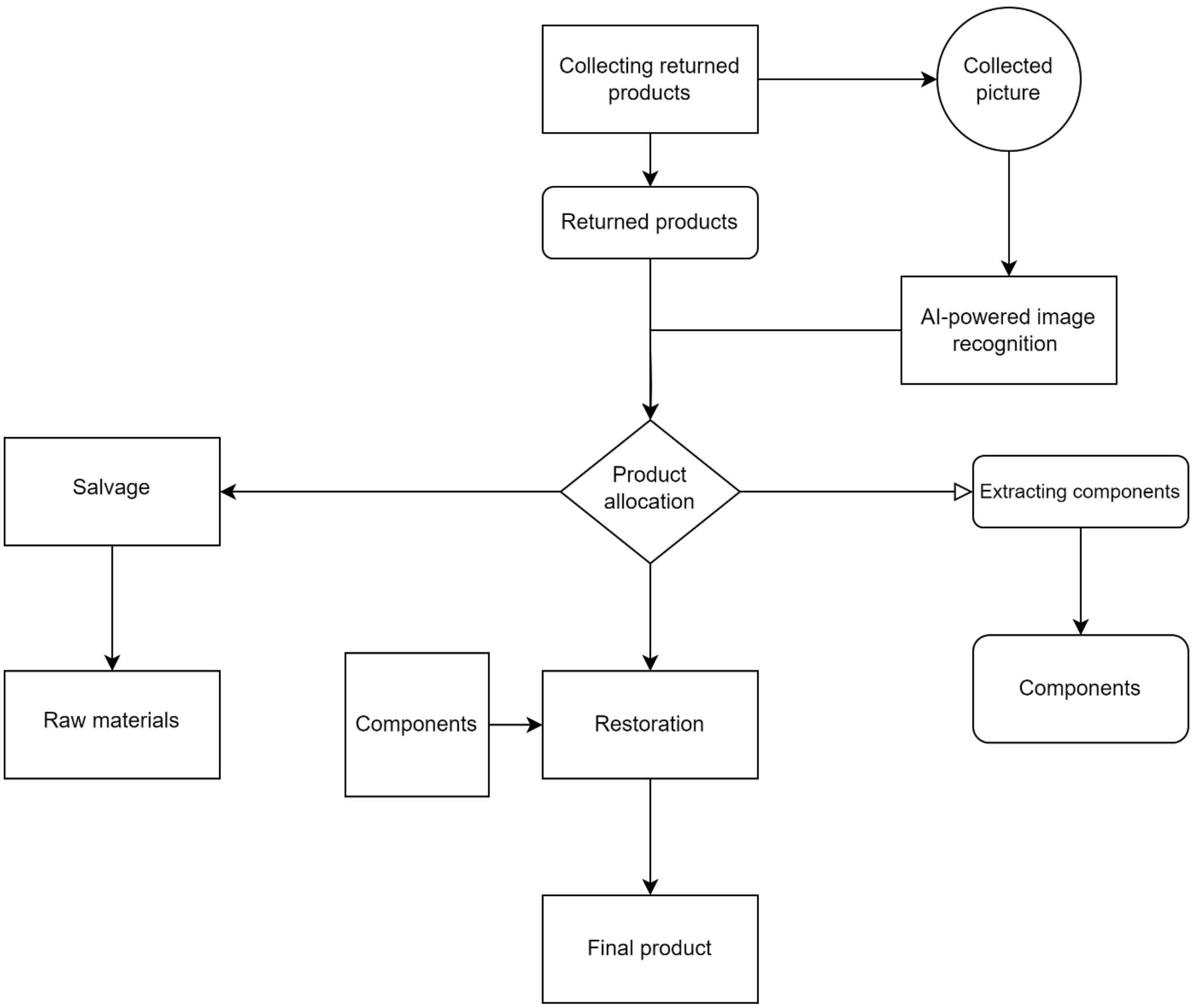

Figure 3. Second scenario AI powered sorting

The objective of this scenario is to study the precision of the IA powered sorting by also taking into consideration the extra cost generated by loss due to sorting that could be generated by misclassification.

Scenario 3: Reverse logistics with additive manufacturing (3D printing).

In order to offer more flexibility in treating returns, we propose to implement additive manufacturing in order to increase to restoration rate of products and offer more gain and flexibility of returned products. The process will be modeled as follow:

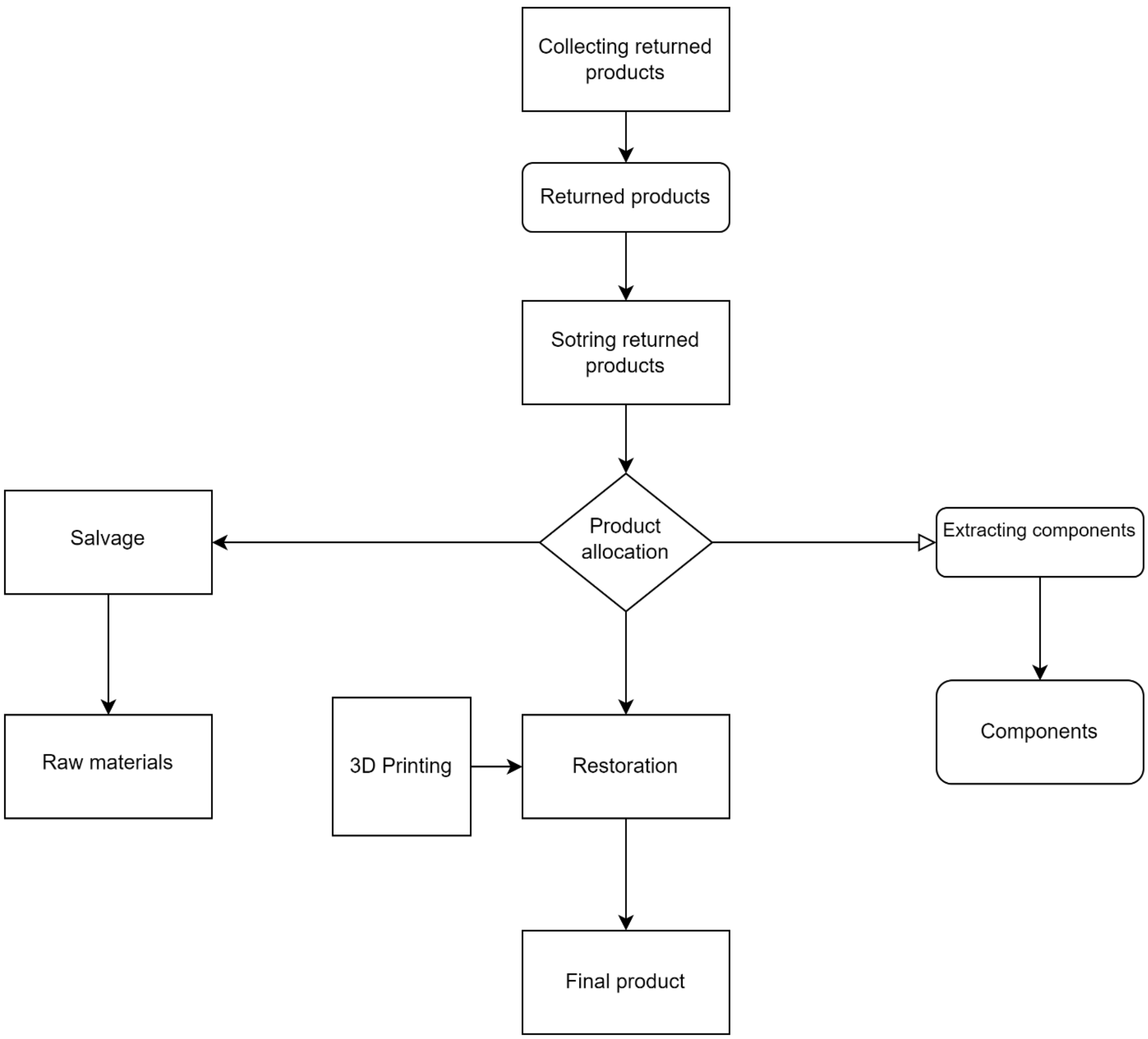

Figure 4. Third scenario additive manufacturing

The objective of this scenario is studying the gain that could be generated from implementing additive manufacturing and reduce the impact on the component's stocks.

5. Results and Discussion

We used ARENA ROCKWEL Simulation software to study the three scenarios. Since our input data was generated using random distribution due to the randomness nature of returned products, we used Monte Carlos' method by running multiple runs of the simulations and study base our study on the average of all results.Since our objective is to analyze the impact of the smart technologies in reverse logistics, we analyzed the variation of the integration of smart technologies:

Table 2. Variation results compared to the classical reverse logistics

	Variations Scenario 2/1	Variation Scenario 3/1
Time needed	- 31.26%	+21.12 %
Reverse logistics' cost	-15.23%	+ 15.71%
Recovered value	-13.25%	+21.13 %
Net gain	+ 17.26%	+18.12

The comparative analysis of Scenarios 2 and 3 relatives to Scenario 1 reveals distinct strategic trade-offs in reverse logistics performance. Scenario 2 demonstrates a significant reduction in processing time (–31.26%) and reverse logistics costs (–15.23%), leading to a net gain increase of +17.26%, despite a decrease in recovered value (–13.25%) due to misallocation by the AI powered sorting that was due to the lack of data to improve the AI machine learning algorithm which could be improved by increasing the input data to increase the learning algorithm for a better efficiency. This suggests that Scenario 2 emphasizes operational efficiency and cost reduction, potentially by simplifying recovery processes or improving logistics flow

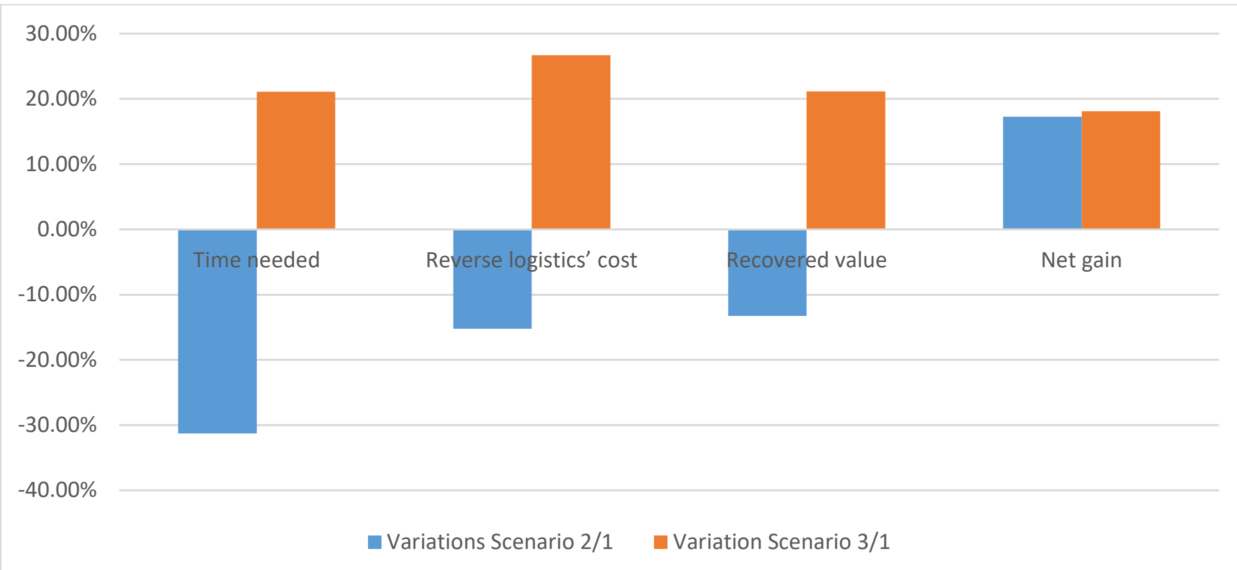

Figure 5. Variation between the classical reverse logistics and after the integration of new technologies

.

In contrast, Scenario 3 exhibits an increase in both processing time (+21.12%) due to the slowed of 3D printing and reverse logistics costs (+15.71%), but achieves a substantial improvement in recovered value (+21.13%) since it could achieve a more precise reparation via additive manufacturing, resulting in a slightly higher net gain of +18.12%. This scenario appears to prioritize the enhancement of product recovery outcomes, possibly through more advanced treatment and refurbishment methods.

Overall, both alternative scenarios outperform the baseline (Scenario 1) in terms of net gain, albeit through different approaches: Scenario 2 leverages cost and time optimization, while Scenario 3 focuses on value maximization from returned products. The choice between the two scenarios depends on the strategic orientation of the enterprise—whether the emphasis is placed on operational efficiency or on maximizing the economic value of reverse logistics.

6. Conclusion

This study highlights the significant potential of smart technologies in improving reverse logistics performance. The comparative analysis of three scenarios demonstrates that smart technology integration can lead to notable enhancements in either operational efficiency (as seen in Scenario 2) or value recovery (as seen in Scenario 3), both contributing to increased net gains compared to the baseline scenario. These findings suggest that smart technologies—such as IoT-enabled tracking, automated sorting systems, and data-driven decision support—can serve as powerful enablers for more sustainable and cost-effective reverse logistics systems.However, several limitations must be acknowledged. First, the scenarios are based on simulated or case-specific data, which may not fully capture the complexity and variability of real-world supply chains. Second, the study focuses primarily on quantitative indicators (time, cost, recovered value, net gain) and does not explore qualitative impacts such as customer satisfaction, employee adaptability, or environmental benefits. Third, the adoption of smart technologies often requires significant upfront investment and organizational change, factors that were not fully integrated into the evaluation model.

Future research should aim to validate these findings through empirical case studies across diverse industries and geographical contexts. Additionally, expanding the analysis to include social and environmental performance indicators, as well as long-term return on investment, would provide a more holistic understanding of the role smart technologies play in shaping next-generation reverse logistics systems.
Future efforts should focus on developing strategic partnerships between government, academia, and industry to support the digital transformation of reverse logistic

References

Beaulieu, M. , Define and control the complexity of logistics networks down. Proceedings of the Third International Meeting for Research in Logistics, Trois-Rivières, Canada, May 9–11, 20 pp,2000.

Beaulieu, M., Martin, R., & Landry, S. ,Reverse logistics: literature review and typology. Group of Sought. CHAIN Notebook 99-01,(1999). Montreal, Canada.

Chiappetta Jabbour, C. J., Jabbour, A. B. L. de S., Foropon, C., & Godinho Filho, M. , When titans meet–Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors. Technological Forecasting and Social Change, 132, 18–25,(2020)..

Demirel, N. O., & Gökçen, H. , A mixed integer programming model for remanufacturing in reverse logistics environment. International Journal of Advanced Manufacturing Technology, 39, 1197–1206, (2008). .

Dubey, R., Gunasekaran, A., Childe, S. J., Wamba, S. F., & Papadopoulos, T. , Big data analytics capability in supply chain agility: The moderating effect of organizational flexibility. Management Decision, 57(8), 2092–2112.

Govindan, K., Fattahi, M., & Keyvanshokooh, E. (2018). Supply chain network design under uncertainty: A comprehensive review and future research directions. European Journal of Operational Research, 263(1), 108–141,(2019). .

Gunasekaran, A., Subramanian, N., & Papadopoulos, T. , "Information technology for sustainable logistics and supply chain management." *Journal of Cleaner Production,2020*.

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. ,Achieving sustainable performance in a data-driven agriculture supply chain: A review for research and applications. International Journal of Production Economics, 219, 179–194,(2020). .

Kocabasoglu, C., Prahinski, C., & Klassen, R. D. Linking forward and reverse supply chain investments: The role of business uncertainty. Journal of Operations Management, 25(6), 1141–116,(2007).

Koot, M., Mes, M., & Iacob, M.-E. Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic. Computers & Industrial Engineering, 158, 107452,(2021). .

Lambert, S., & Riopel, D. Reverse logistics: A review of literature. GERAD, Department of Mathematics and Industrial Engineering, École Polytechnique de Montréal, PO Box 6079, Station Centre-ville, Montreal (Quebec), H3C 3A7, Canada.

Prahinski, C., & Kocabasoglu, C. Empirical research opportunities in reverse supply chains. Omega, 34(6), 519–532,(2006). .

Rahman, M. A., Sarker, B. R., & Escobar, L. A. ,Peak demand forecasting for a seasonal product using Bayesian approach. Journal of the Operational Research Society, 62, 1019–1028,(2011).

Reimer, D. , Title of the paper. Proceedings of the 5th North American International Conference on Industrial Engineering and Operations Management, Detroit, Michigan, USA, August 10–14, pp. xx–xx,(2020). .

Reimer, D., & Ali, A. ,Engineering education and the entrepreneurial mindset at Lawrence Tech. Proceedings of the 3rd Annual International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, July 3–6, vol. xx, pp. xx–xx,(2012). .

Reimer, D., Islam, T., & Ali, A. ,Engineering education and the entrepreneurial mindset at Lawrence Tech. Proceedings of the 12th Annual International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, July 3–6, vol. xx, pp. xx–xx,(2012). . https://doi.org/10.46254/AN4.12.202201

Shahparvari, S., Soleimani, H., Govindan, K., Bodaghi, B., Fard, M. T., & Jafari, H. ,Closing the loop: Redesigning sustainable reverse logistics network in uncertain supply chains. Computers & Industrial Engineering, 157, 107093,(2021). .

Shetty, D., Ali, A., & Cummings, R. ,A model to assess lean thinking manufacturing initiatives. International Journal of Lean Six Sigma, 1(4), 310–334(2010). ,.

Koot et al., Koot, M., Mes, M., & Iacob, M.-E., "Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic," Computers & Industrial Engineering, vol. 158, pp. 107452, 2021

Wamba, S. F., & Queiroz, M. M. (2020). "Industry 4.0 and the supply chain digital transformation." *Supply Chain Management Review*, 2020.

Biographies

Faycal MIMOUNI is a researcher of Industrial Engineering in Laboratory of advanced systems engineering (ISA) at ENSA and EST at Ibn Tofail University in Kenitra. He earned engineering degree in industrial Engineering from EMI Mohamadia school of engineering, Rabat, Morocco. And after that he started his doctoral studies in reverse logistics at ENSA at university Ibn Tofail. His research interests include quality, reverse logistics, simulation, industry 4.0, supply chain, optimization, studies on reducing CO_2 emissions and manufacturing systems. He co-supervises 3 doctoral students at university. Also, his research published in indexed journals and presented at international conferences contributes to advancing knowledge in supply chain management and mainly reverse logistics with expansion to the green logistics. It follows an applied approach aimed at fostering collaboration between academic and industrial stakeholders to develop innovative logistics solutions.

OSSAMA AOUANE is a researcher at the Laboratory of Marketing and Strategic Analysis of Organizations (LAMSO) at ENCG Casablanca, affiliated with Hassan II University of Casablanca, his research focuses on supply chain management and the optimization of logistics and port performance PhD in Management Sciences, specializing in logistics, and a graduate of the Faculty of Legal, Economic, and Social Sciences of Ain Chock.
His research, published in indexed journals and presented at international conferences, contributes to advancing knowledge in supply chain management. It follows an applied approach aimed at fostering collaboration between academic and industrial stakeholders to develop innovative logistics solutions.

Rabiî EL GOMRI has PhD in Engineering and Logistics Systems Management from the University of Brussels, with over 10 years of experience in higher education and consulting in logistics professions. He is currently holding the position of Professor and Researcher in Supply Chain Management at the Higher Institute of Transport and Logistics (ISTL).

Driss SERROU Has PhD in Industrial Engineering and Logistics: ENSA Kenitra Systems Engineering. Morocco with over 15 years of experience in higher education and industrial company. He is currently holding the position of Professor at Ibn Tofail University in Kenitra -Morocco , and Researcher is a researcher of Industrial Engineering in Laboratory of advanced systems engineering (ISA) at ENSA and EST at Ibn Tofail University in Kenitra , His research interests include : Logistics , maintenance 4,0, production , IA