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Approaching the re-design of reusable packaging from an environmental perspective: a case study in the railway sector

Approaching the re-design of reusable packaging from an environmental perspective: a case study in the railway sector

Berzi L.*, Cocci M, Barbieri, R., Pierini, M., Delogu M.
Università Degli Studi di Firenze, Department of Industrial Engineering DIEF, 50139 Florence (FI), Italy

*email: lorenzo.berzi@unifi.it

Abstract.
The production of railway vehicles determines the handling of a large amount of materials which are transferred from suppliers to production site using industrial packaging. The activity here described is part of the MORIMB project, which dealt with the reduction of waste related to railway sector; wood, plastic, cardboard and metal fasteners are the typical materials which are adopted for such packaging.
The study is motivated from the evidence that, due to the peculiarities of the transported components, most of the packaging units were different from standardized formats therefore they were frequently used for a single transport and subsequently scrapped. An applicative methodology for the analysis, redesign, and evaluation of environmental and economic impacts was defined, with particular attention to packaging reusability. An adaptation of the DMAIC approach was used to analyze the various components and find solutions reusability and performance improvement, especially in terms of volume efficiency and component protection. Depending on the item to be transported, specific crates have been designed and structurally verified according to existing technical regulation, and their sustainability has been analyzed considering environmental and economic impact during production, transport and storage phase; appropriate scenarios regarding distance travelled and volume occupancy were defined. The case study presented in detail in this work concerns the concept of special crates for the transport of passenger seats – a key component for train production - for which an increase in packaging density and a reduction of transportation costs was achieved. Other case studies were also considered.

1. Introduction

The impact related to packaging is well known as a cause of relevant impact for consumer and industrial products. Due to the increasing sensitiveness to the environmental impact, since the last decade of the XXth century a tendency to the reduction and optimization of packaging waste is started. Various studies [1] highlight that the substitution of single-use packaging in favor of reusable packaging can support waste reduction, environmental indicators improvement and, under certain conditions, economic advantages; in other words, reusable packages are potentially more sustainable. In this context, our analysis is focused on the production of complex machines such as railway vehicles, which determines relevant material handling needs due to the transport of delicate components and materials from suppliers to the main manufacturing and assembly site. Such activities can be defined as *transit transports* according to [2], and include the use many different solutions such as boxes, containers, crates, pallets and wrappers. The MORIMB project deals with the reduction of waste materials from the packaging used to handle the materials (namely, finished components and parts ready to be applied on the main vehicle assembly) supplied to Hitachi Rail STS site (HRS), located in Pistoia (PT, Italy). The motivation is based on the evidence that a relevant amount of packaging used by the Company is tailored on specific applications, since standardized formats cannot satisfy the requirements in terms of protection during transport and performances during warehouse storage. The consequence of such approach is that relevant amount of packaging devices are scrapped after a single use; therefore main target of the activity is the reduction of such events and the definition of devices enabling transport to the Company and take-back logistics to the suppliers. From a preliminary study we are noted that the waste produced in recent years is very high, and comprehends into wood, plastic, cardboard and metals, these latter especially for fasteners and similar parts. The present text illustrates the definition and the application of a methodology for the improvement of the sustainability profile of packaging applied on this sector and is organized as follows: section 2 describes the approach and main indicators and boundary conditions adopted for the study; section 3 is focused on the development of a relevant case study; section 4 provides final observation and remarks.

2. Methodology

An adapted DMAIC - Define, Measure, Analyze, Improve and Control - algorithm was used to find improvement solutions compared to the existing situation. The approach is aimed at enhancing the environmental profile of the HRS company according to the target of continuously improvement set by internal policy. According to the indications provided by the industrial partner, the project focused on a group of representative packaging units to be used as case study on which, through the application of the adapted DMAIC methodology, we defined a packaging waste reduction model that can be adopted and transferred to similar products. Main phases are:

- DEFINE: Two products were selected as reference case studies, namely the “Caravaggio” and “Masaccio”. These railway vehicles are planned as long-term orders and they will be under production for a time frame compatible with the implementation of new practices. The possible case studies of components were selected due to the large quantity needed to set up a train and the volume occupied in the warehouse, and also on the basis internal know-how and operation needs.
- MEASURE AND ANALYZE: The materials involved for the various packaging and the quantities involved were analyzed, evaluating the costs of preparing the packaging unit, packing, transporting, unpacking, waste disposal, and warehouse storage; all these are part of the typical life. In addition, loss related to the damage of components due to non-compliances were considered, assuming that due to packaging re-design such events will be further reduced. The LCA (Life Cycle Assessment) approach was used to evaluate the current impact of packaging, as described below.
- IMPROVE: In this phase, the packaging was redesigned according to new requirements and specification; the output of such phase is the creation of a CAD model and a subsequent Finite Element Model (FEM) analysis to verify the coherence with design requirements; relevant solicitation can arise during transportation in road vehicles and warehouse stacking. In this phase, the costs for the creation of the new packaging were also evaluated, creating economic accounts and differential statements to evaluate the economic sustainability of these investments.
- CONTROL: After the selection of priority components which should adopt the newly designed components, implementation and control will follow. Such phase includes the inclusion of a number of prototypes to verify the effectiveness of the new packaging, the real-world cost and their functionality. Particular attention should be paid on the acceptance of the new approach by suppliers. Control phase therefore include Mid and Long term objectives aimed at continuously verify the effectiveness of the initiative and the correspondence to the target, eventually providing warnings in case of non-conformities and stimulation a reaction, which potentially starts back from Measure, Analyze and Improve phases. Particular attention is expected to be paid on the inverse logistics, which is not part of current practices and could imply iterative steps to be implemented and optimized over the time.

A few notes are necessary regarding the indicators adopted. For the assessment of the lifetime impact of the application, a simplified framework for the Environmental and Economic impact has been considered:

- Economic impact has been based on the measured costs (known by the Company) and other hypothesized costs derived for the design phase. Due to the relevant investment foreseen for the introduction of reusable packaging, the Internal Rate of Return IRR has been estimated on the basis of the expected product life.
- Environmental impact has been based on the assessment of GWP (Global Warming Potential) indicator of reference and new packaging unit, expressed as kg_{CO2_eq}.

The environmental impact has been estimated on the basis of two main sources. For existing and newly designed packages the use of CAD-integrated sustainability software such as the Solidworks Sustainability tool [3] has been adopted; due to the adoption of known materials (wood, metal, plastics etc.) and of conventional manufacturing technologies all main information were available. In order to provide information related to the direct and take-back transportation activities, data have also been extracted by the Sphera-Gabi software, considering proper transportation routes (e.g. by maritime or road transport) depending on the supplier, on its distance to the Company and on the expected occupancy of typical containers.

For both economic and environmental indicators, the identification of correct and up-to-date information required a strong interaction with the whole supply chain, as typical for improvement project.

During the design phase a relevant performance improvement target has been set: the reduction of total volume occupied in the warehouse for the supply of typical vehicle set (e.g. the stock of seats necessary for one carriage). The target has been achieved both providing resistance to multiple stacking and increasing the unused volume in a single package, designing tailored part housings and fastenings. Due to increase of the mass contained, the new packaging will have to comply to more restrictive requirements compared to the current situation, dealing with stability and resistance requirements, for example during road vehicle transportation [4]. Main design targets for the reusable packaging include:

- Life from 5 to 10 years.
- Significant volume reduction for the take-back phase, to be achieved using foldable parts but excluding part dismantling/separation.
- Stacking capability to improve warehouse utilization coefficient.
- Safety according to known best practices.
- Compatibility with conventional forklift handling.

3. Analysis of the proposed case studies.

3.1. The seats assembly case study

Considering the characteristics of the railway vehicles, various components were analyzed: the seats, interior trim, toilets, windows, panels and so on, focusing on body parts rather than on mechanical parts. See Figure 1 for a typical vehicle layout.

The priority for the adoption of the reusability criteria on these parts was unknown but, as a first case study, a component widely used was examined, namely the seats. Each carriage has on average around 60 seats, and each railway train of the Masaccio and Caravaggio, regional orders, is made up of 3 to 6 carriages. The quantity of seats fitted and the types of seats change based on the type of setup. Double seats, triple seats and benches are mounted and are divided into various types based on the position in which they must be installed.

Figure 2 shows two types of seats, which can be organized in double and triple assemblies; these two types are divided into right and left, with guides underneath and without guides. As visible in figure, such component is provided in mixed wood-cardboard boxes, which can be stacked on a maximum of three units. Such AS-IS condition has been analyzed considering the materials necessary to create each package, the quantities necessary to create a carriage; the costs and environmental impact deriving from them.

Figure 1. Seating layout of typical reference vehicle.

Figure 2. Seat packaging with waste materials

A pallet is made up of three boxes which contain a total of three seats, the dimensions of the boxes are 1120 mm wide, 1120 mm long and 530 mm high. In each pallet the packaging consists of 27 kg of cardboard, 16 kg of wood and 0.95 kg of plastic. This packaging is usually scrapped after one service. As said, the Global Warming Potential is adopted as an index to evaluate the environmental impact and the adopted data are reported in Table 1.

Table 1. Environmental impact data

Base material (1 kg)	Material and production	Transport kg_{CO2}/km*kg	End of life
GWP Wood	0,793	5,43E-05	0,506
GWP Card board	1,172	5,43E-05	0,035
GWP Plastic	2,859	5,43E-05	0,676
GWP Steel	0,756	5,43E-05	0,023

Figure 3 shows the impact in terms of CO2 equivalent for each material referring to a single seat. The analysis was conducted considering the various production phases from materials, to manufacturing, to transport and to end of life. Packaging for a seat has an impact of approximately 19.74 kg of CO_2

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equivalent, the calculation also considering the transport from the manufacturer to HRS, in the city of Pistoia.

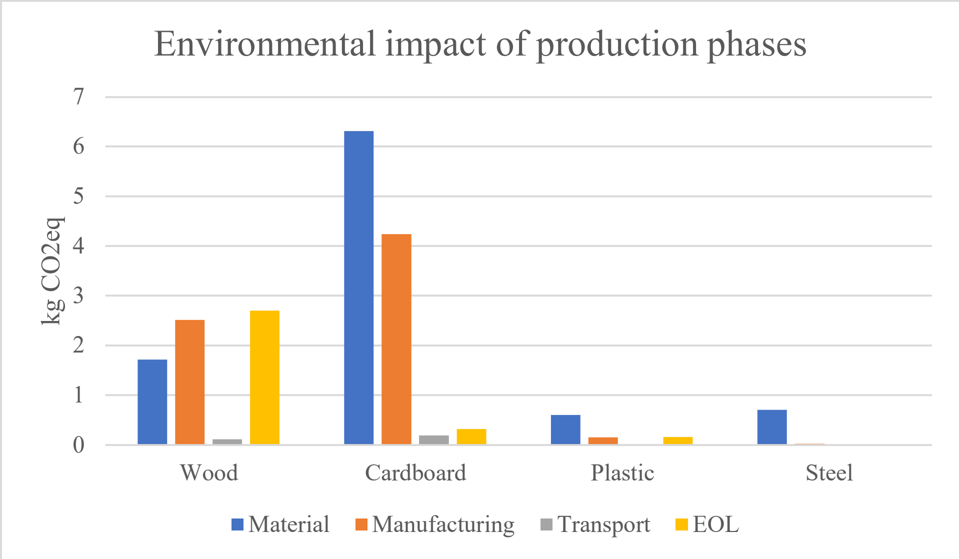

Figure 3. Environmental impact related to a seat

The costs deriving from the manufacturing of the packaging have been calculated, using data coming from market analysis and from interaction with supply chain. The cost of the wooden platform, the cardboard and the plastic present in each package were considered and subsequently normalized by referring them to each seat. Furthermore, the labor to assemble the packaging was also considered. The costs from the supplier to HRS were considered in the transport costs and the costs for internal handling, storage and unpacking were also considered. Instead, the costs of disposing of the various materials including internal movements were considered in the disposal costs.
The costs for the manufacturing of each package represent approximately 50% of the costs and another 40% is derived from the transport and storage phase, as shown in Figure 4.

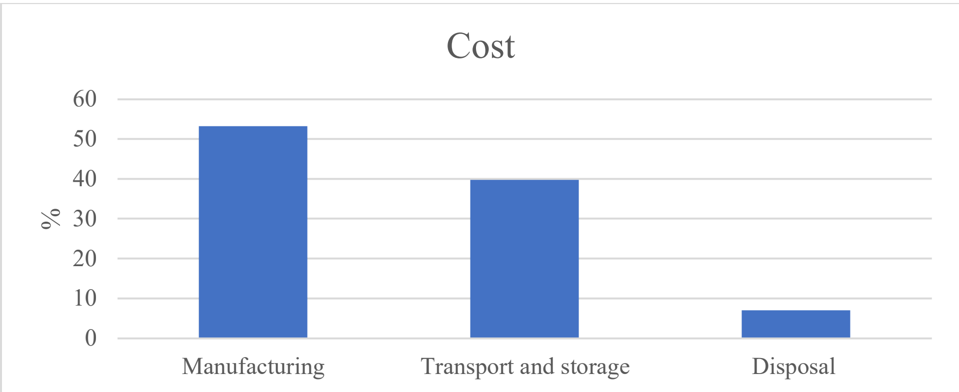

Figure 4. Normalized cost breakdown for seat assembly.

This type of packaging does not allow stacking on multiple levels, as the cardboard boxes deform and lead to non-conformity of the internal component, as parts of the internal seat coverings can be damaged. In the IMPROVE phase, where the packaging is redesigned, it was considered that the new packaging had to respond to various requirements: better use of the warehouse, better effectiveness of the new packaging with reduction of non-conformities, better compaction of the packaging in transport, reduction of waste materials by creating reusable and compactible packaging, better compaction factor of the material transported inside the packaging, increase in packaging safety. A packaging was created that could satisfy all the previously defined requirements, as shown in Figure 5.

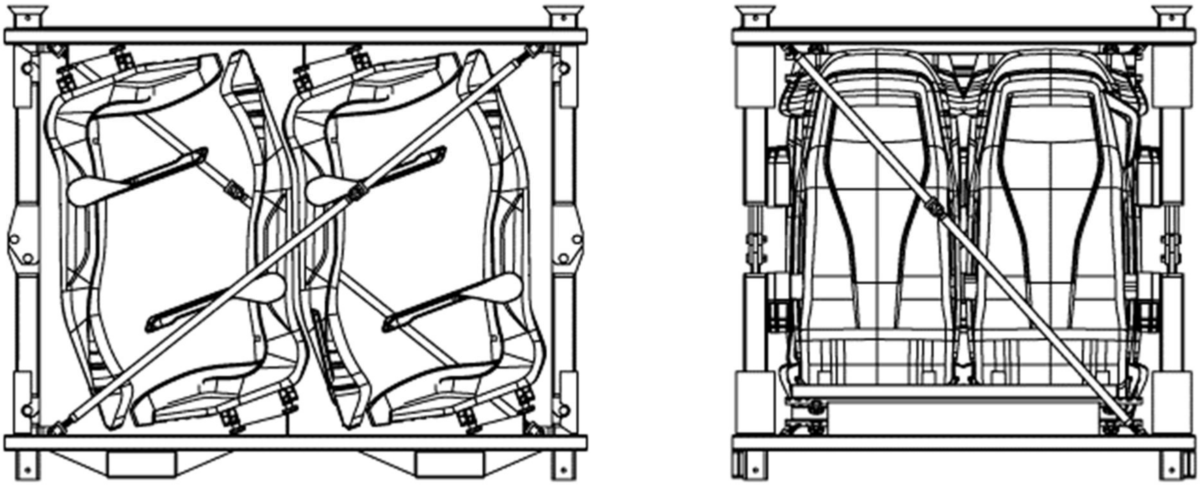

Figure 5. New reusable and foldable housing for seat assembly; 4 units of 2-seats version are contained.

A package was created that could contain four seats assembly (8 seats in total) to improve the packing factor. The packaging is foldable in order to improve the packaging factor when returning the packaging to the manufacturer. It was possible to achieve this by creating special hinges secured with pins that can be easily removed by any operator. The seats are fixed on slides, stopped with manual tightening systems, easily extractable by operators, as shown in Figure 6.

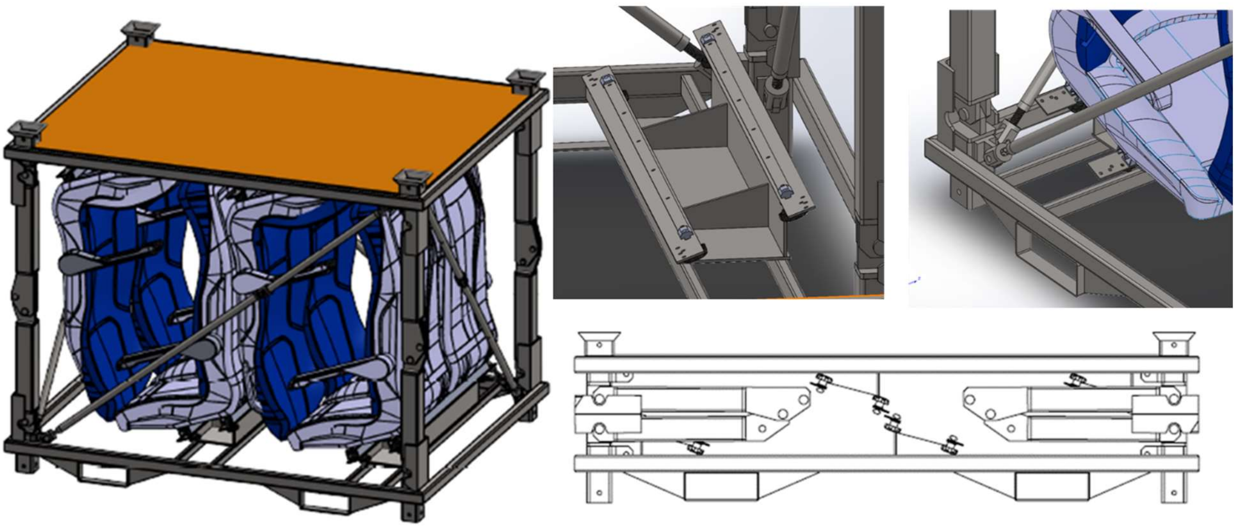

Figure 6. Details of the new assembly in transport and take-back status.

Furthermore, to avoid any lateral movement of the seats, locking pins have been provided. The EN 12195 standard [5] provides that during transport a package is subject to lateral accelerations equal to 0.8 g in the event of emergency braking, while accelerations equal to 0.5 g in the case of a curve, in which case the acceleration is directed at 90 degrees respect to the previous case; such boundary conditions were used to estimate the stresses and deformations acting on the packaging. The represented packaging unit is the solution obtained at the end of verification and correction phase, and is compliant to such solicitation.

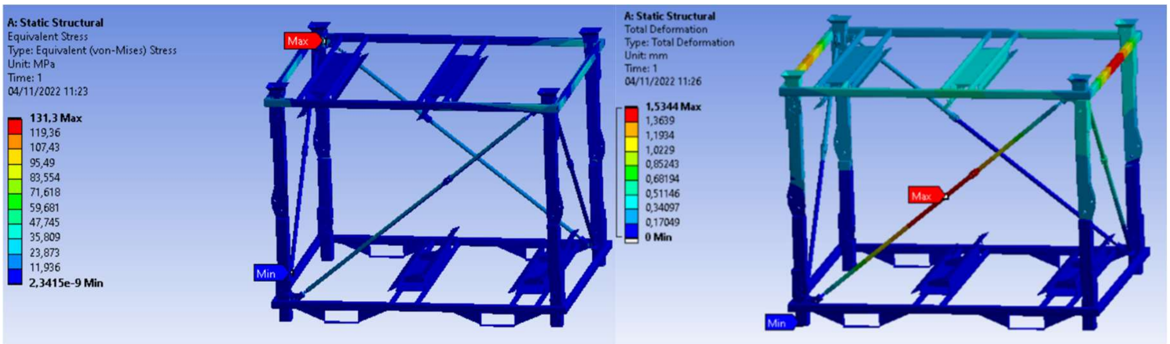

Figure 7. Finite element analysis, stress and strain.

Figure 7 shows that the maximum stresses never exceed 132 MPa, with maximum deformations. equal to 1.6 mm. It should be noted that each complete package can achieve a mass of approximately 250 kg, the metal foldable container accounting for approximately 120 kg. Such relevant mass, as demonstrated below, is not hindering the achievement of satisfactory environmental performances since for the reference case the saturation of the volume of container or of road vehicles loading platform typically occurs in terms of volume rather than in term of mass.

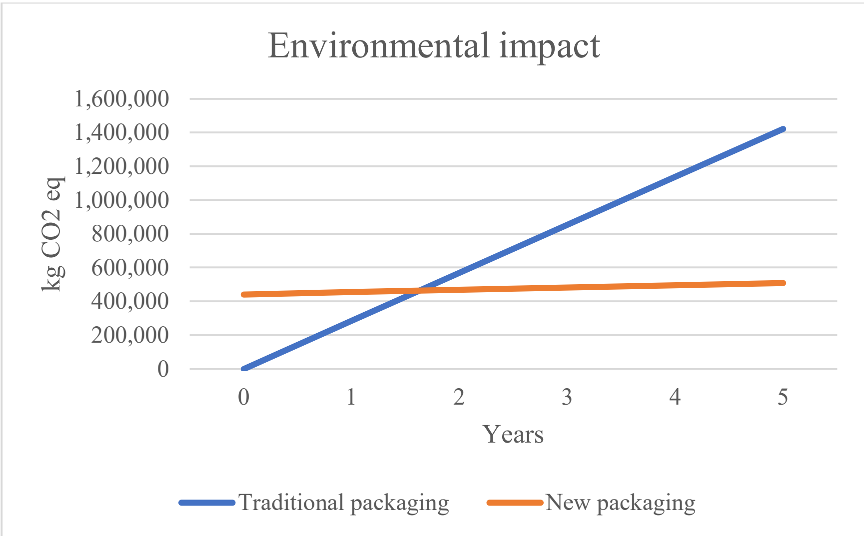

Figure 8. Environmental impact comparison.

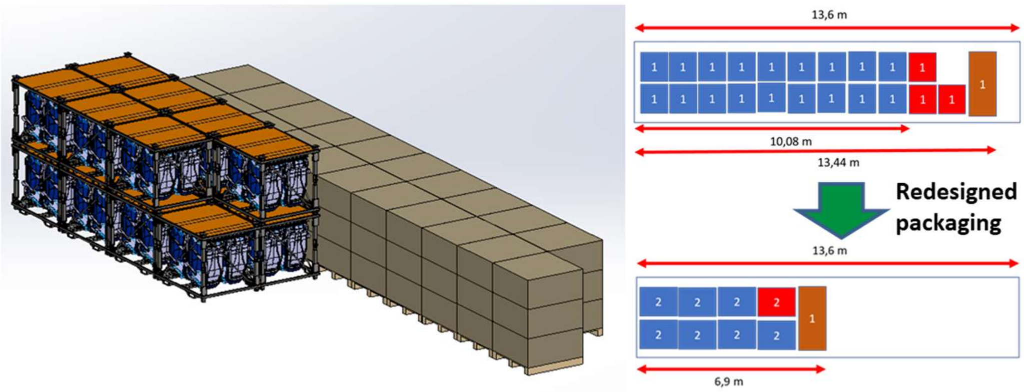

Figure 9. Comparison of the as-is and to-be packaging during transport. Right: Example of volume to be transported reduction for a same supply. Left: Occupancy of a transport container; blue, red and brown blocks correspond to different seat models, all being part of the same vehicle.

A comparative LCA analysis was performed between the current situation and with the redesigned packaging. The analysis is expressed as a parametric calculation over the years of adoption considering the environmental impact of the material, the manufacturing of the new packaging, the transport and its end of life both for reference and to-be case study.
Figure 8 shows that for the seat assembly case study the new packaging achieves environmental impact break-even-point in less than two years. Figure 9 shows that with the redesigned packaging it is possible to reduce the volume occupied during transport, approximately doubling the number of seats transported in comparison with the as-is situation. With the redesigned packaging it was also possible to optimize the space occupied in the warehouse, making better use of the spaces available and taking advantage of the entire height of the magazine. Figure 10 shows that a kit with the current packaging occupies approximately 18 m^2 while the new packaging will occupy approximately 7 m^2 for the same kit. For the comparison, as a conservative hypothesis it was assumed that conventional packaging would be stacked up to a 6 levels, which is mostly unfeasible due to resistance issues.

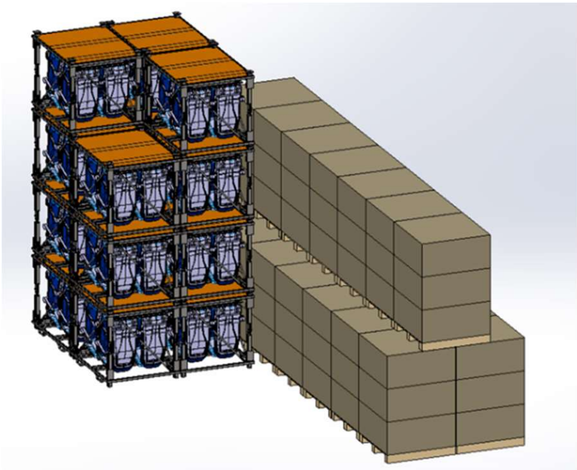

Figure 10. Comparison of the warehouse occupancy with baselined (brown) and redesigned packaging.

To evaluate whether this investment is also sustainable from an economic point of view, an economic analysis and a differential report were carried out between the current situation and the one with the redesigned packaging. Such result is shown in term of value over the initial investement.

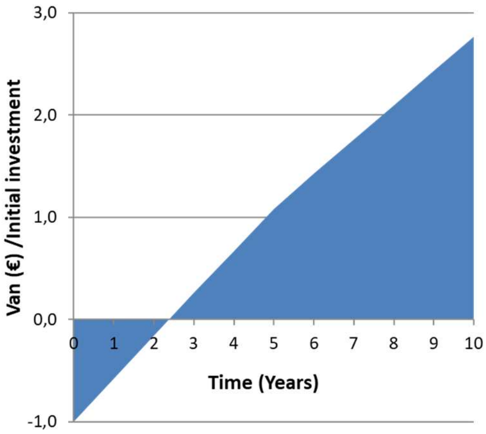

Figure 11. IRR of the proposed solution.

Figure 11 shows that the return on investment will take around 2 and a half years. The redesign of the packaging allows for a reduction of 2.8% in the annual waste produced by the company deriving from the wood used to make the packaging and by 35.5% from cardboard.

3.2. Railway vehicle components case studies.
The defined approach has been applied on other components such as interiors, windows, toilets, and other relevant vehicle body parts, in order to find out the priorities for the implementation of the reusable packaging, considering the need for an initial investment as demonstrated by the seats assembly case studies. Similarly, customized packaging were created, maintaining the requirements of foldability and introducing the possibility to provide reconfiguration for different components after the end of the order. In addition, a number of components to be provided as initial investment was suggested on the basis of the expected supply needs. Table 2 shows the number of packages to be created for each component analyzed, the breakeven point, the internal rate of return of each investment and the space saved in the warehouse. Considering the implementation of all solutions, the breakeven point of the analyzed components will be achieved approximately in two years and three months. The investments allow for a profitability of the investment equal to 37% and can reduce the space occupied in the warehouse by approximately 517 m^2.

Table 2. Economic summary for the implementation of the reusable packaging on other vehicle parts.

Description	Necessary reusable package units	BEP (Break Even Point)	IRR (Internal Rate of Return)	Volume saving
Seats	390	2 years, 8 months	34%	311 m^2
Interior 366	40	1 year, 2 months	81%	34 m^2
Interior 367	40	3 years	21%	30 m^2
Interior 500	40	1 year	96%	35 m^2
Interior 375	40	1 year	102%	14 m^2
Toilette HK	8	1 year, 4 months	74%	21 m^2
Toilette St	8	1 year, 7 months	69%	9 m^2
Windows	60	3 years, 1 month	21%	30 m^2
Veils	40	1 year, 11 months	49%	25 m^2
Vestibule	40	2 years, 9 months	27%	8 m^2
Total		2 years and 3 months	37%	517 m^2

Table 3 shows the reduction in waste that was possible to achieve for each component analyzed in relation to the total produced by the company and the reduction in terms of CO_2 equivalent. Furthermore, it can be observed in Figure 12 that the breakeven point from an environmental point of view is less than two years.

Table 3. Environmental summary. The baseline amount for the total percentage calculation is the total amount of that material inside the Company.

Description	Waste change in 5 years			GWP variation in 5 years ($t_{CO2\ eq}$)
	Wood (kg)	Cardboard (kg)	Plastic (kg)	
Seats	2.8%	35.5%		911
Interior 366	0.8%		5.8%	134
Interior 367	0.5%			14
Interior 500	1.1%			147
Interior 375	0.3%			44
Toilette HK	0.3%			16
Toilette St	0.1%	0.1%		0.8
Windows	0.6%		1.0%	37

Veils	0.5%		0.7%	36
Vestibule	0.5%		1.1%	64
Total	7.6%	35.6%	8.6%	1408

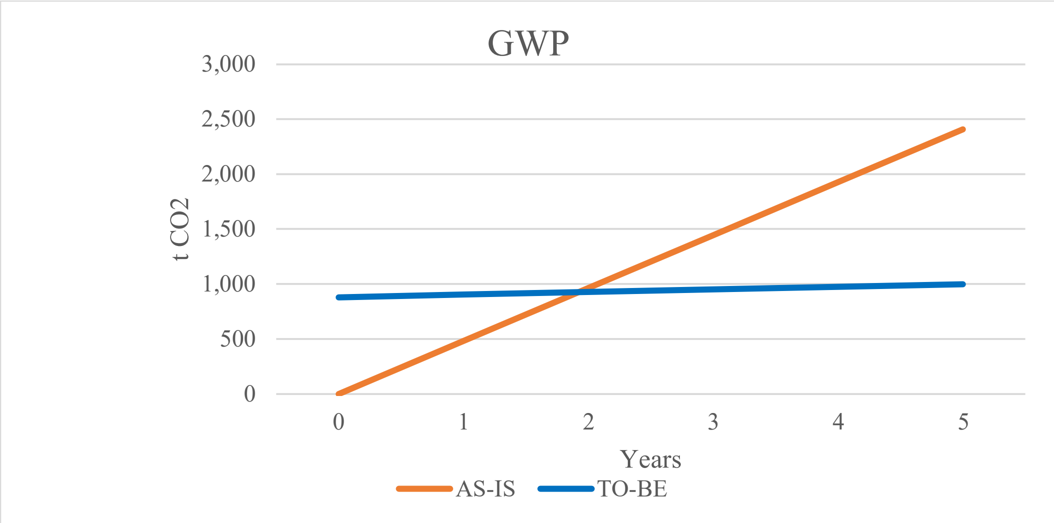

Figure 12. Environmental summary. Comparison of GWP impact for the "as is" and the "to be" solution considering the adoption of reusable packaging units for all the elements listed in Table 2 and Table 3.

4. Conclusions

The transit and storage of the components needed to produce a complex product such as a railway vehicles imply the manufacturing, the transport, the use of a remarkable amount of materials which, in the current practice, are frequently scrapped at the end of their service, best case being their recycling; reusability is hindered by the special format adopted for large and specific railway components. Due to the presence of repeatable supplies for the body of typical carriages, a re-design action has been described using the data for two different vehicles produced at HRS Company. Such activity implied the application of good design practices monitored by the adoption of environmental and economic indicators, used to assess the effective advantages of reusable components. Despite of the take-back costs, the results clearly indicates that for a large number of component categories relevant advantages are possible, main one being the volume reduction both in transportation and storage phase.

However, the need for a proper design of the packages highlights the need for accurate engineering design, proper management, and strong collaboration with supplier. It is therefore possible the adoption of such reusable packaging units has been hindered up to know by the initial barrier represented by the investment costs.

During MORIMB project various components were considered using primary and secondary data to demonstrate the potential, while the implementation is running in terms of detailed packaging design and manufacturing, which will be followed by implementation and supply chain modification. The approach defined within the activity is potentially able for implementation to other industrial case studies both in HRS and in other contexts.

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