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Article

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ORIGINAL ARTICLE

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Automation in cargo loading/unloading processes: do unmanned loading technologies bring benefits when both purchase and operational cost are considered?

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Abstract

The use of technologies that automate handling goods and loading units in warehouses and depots is not new. Yet, the purchase process of these technologies issues troubles and the estimation of the economic advantages brought by one or another technology to the entire chain of operations in logistics are not always known. Faults or not documented decisions put pressure on managers and prices for services. They can cause a drop in the competitiveness of warehouse operators, particularly in uncertain conditions. Academia documented the cost of warehouse storage well. Yet, little research has looked into the economic justification of implementing automatic systems for loading or unloading activities and the impact on complementary operations. For this reason, a model is needed to calculate the cost of operations when different technical equipment is used. This research further investigates the cost categories that must be considered when purchasing automated loading/unloading technologies. The model includes the purchase and operational loading costs that new technologies generate and the cost of adjacent operations to loading activity. The case study uses forklifts as the reference scenario and provides an overview of the return on investment and a break-even period when other technologies are in use. The calculation model shows that increasing cargo volume leads to a better RoI. The same observation is also made regarding the rise in labour costs. For the latter, using human operators to handle pallets on a one-by-one basis generates an exponential increase in operational cost due to delays and faults. On the other side, the cost of implementing automated loading/unloading technologies and the consideration of technology risk determine the low economic advantages. An in-depth cost and benefit analysis shows in which situation a technology generates greater benefits. Further results of this paper show that better use of trucks' loading capacity can positively impact the financial performance of automated loading technologies, as a higher volume of cargo is moved (at once) without human intervention.

Keywords: Automation, Cost and benefits, Return on investment, Loading and unloading technologies

Introduction

The changes that technologies bring to operations in warehousing have been researched since the early '70 s. The focus of research back then was to determine the optimal storage assignment and to investigate how technology can help. By mean that new technologies arrive, they bring changes throughout the supply chain, and comparing different technologies becomes a complex process.

Hausman et al. (1976) compare the operating performance of three storage assignment rules and show how the storage infrastructure design influences the throughput capacity. Ozden (1988) builds more on the same theory and focuses research on applications of automated guided vehicles in warehouses. Up to that date, this type of cargo moving and loading technology has been characterised by a simple mode of operation, namely single-load-carrying capacity for each vehicle and unidirectional traffic (e.g. cargo being set for loading in a buffer zone cannot be called back) on each route of the system. In the new cargo and models analysed, bidirectional traffic is allowed, which shows the impact of changes in the throughput capacity. Within operations handled automatically in warehouses, a significant amount of research looks at automated guided vehicles (AGV). For example, Hwi Kim and Hwang (1999) propose a new dispatching algorithm for the efficient operation of AGVs. It has an adaptive control capability to respond to system environment changes based on an evolutionary operation. The results are provided from a sensitivity analysis that varies the buffer capacity. Yet, they do not give any effects concerning the economic implications of varying the buffer time considered in handling operations or the cost of implementing and use of this technology.

Equally, Takakuwa et al. (2000) examine the simulation and made an economic analysis of non-automated distribution warehouses. They build a model designed to generate the parameters of materials handling. They focus on determining the operational cost parameters for the following activities: loading and unloading, movement to and from storage, and order filling. Yet, the costs of operations for preparing the cargo for loading and/or unloading are not covered in their parameter simulation. Concerning the justification of capital investment, Ioannou and Sullivan (1999) deliver results by introducing capital investment as a contributing element to the decision-making of investing in automated material handling systems. Yet, the reference scenario refers to the labour cost as the main and only element to be compared with automated equipment.

More recent research, like Brambilla et al (2013), discusses the collective digital systems called 'swarms'. These can be found in the literature in swarm intelligence (Al-Obaidy and Al-Azawi 2019) or swarm robotics (Schranz et al. 2020). One of the main characteristics of these systems is that they can reconfigure themselves. By adding the characteristics of the swarm technology to a production line, its robustness is expected to increase. Adding this property to industrial processes results in capabilities that allow dynamic changes in the production process. Yet, no economics-based perspective is provided concerning the implementation or use of this system or its impact on truck loading/unloading operations.

In the logistics sector, all operations revolve around an increase in service levels (reliability), efficiency, and speed (Cano et al. 2021). Yet, truck drivers, order pickers or warehouse operators still spend significant time waiting at the loading docks before their trailers can be loaded or unloaded. Most loading and unloading

operations are done with manual labour, which is time-consuming and prone to errors, damages, and accidents. With an increasing hour wage and shortage of truck drivers, there is a clear need to improve these operations. Yet, the changes in processes where these technologies are used bring as well troubles further in the logistics chain, as changes are required as well to technologies that are used for moving cargo within warehouses, transporting or doing inventory management. The economic advantages brought by one or another technology are not always known or cannot be estimated entirely.

The decision bodies make then thus decisions based on short-term estimations and information available through one-time market prospects, as shown by recent research (Richey et al. 2022) that has looked into the opportunistic behaviour of purchasing professionals. Gelderman et al. (2020) show that opportunistic behaviour often appears to be a conscious choice by a purchaser based on a balanced assessment of risks and consequences. In addition, the same research demonstrates that purchasers regularly act on explicit instructions from their superiors, or they feel pressure to achieve short-term results or are compelled to follow unworkable procedures and protocols. In this context, having a tool that could show the expected economic impact of a specific technology in the medium term and which offers the possibility to quantify technology risks is critical.

Therefore, the impact of an autonomous loading and unloading system for trucks is analysed by considering the purchase process and operational costs. For this purpose, a tool based on a mathematical model is developed. The tool is validated using a case study from an existing company that wants to invest in an automated truck loading and unloading system.

This paper aims to develop a general tool that supports managers responsible for automation in an organisation in selecting and purchasing suitable automated loading/unloading technologies (ALUT) for a specific warehouse operation (loading/unloading trucks).

The following research questions are formulated:

RQ1 How can a cost model be developed that supports the decision-making for implementing automatic loading-unloading technologies?

RQ2 Which types of ALUT should be considered for truck loading?

RQ3 Is there a positive return on investment from implementing automatic loading-unloading technologies?

The structure of the paper is as follows. “[Literature](#)” Section presents the results of the literature study. “[Research approach](#)” Section provides the approach used for further research. “[Costs elements and the RoI model of ALUT](#)” Section presents the model developed. “[Loading and unloading technological solutions](#)” Section provides the list of analysed ALUT. “[Case study](#)” Section performs the case analysis. “[Conclusions](#)” finally provides the main conclusions and discusses further applications of the return on investment (RoI) calculation model.

Literature

The literature review below gives an overview of the advancements made in automation in logistics and frames the issue addressed by the present paper.

The 4th Industrial Revolution (Industry 4.0) increases the digital capabilities of industrial systems in production lines (Qin et al. 2016) by allowing them to communicate and exchange data in real-time (Fonseca 2018). Fundamentally, automation in a warehouse is not new. Yet, there is evidence that the effects of technological advancements remain unaddressed by up-to-date research. Such systems complement the hardware equipment used to execute operational cargo movements within warehouses and make the logistics chain 'smart' at the system level rather than at the level of an individual link in the production chain. From this perspective, it is essential to notice the changes occurring at all logistics chain activities: inventory management, internal transport, loading/unloading or the adjacent transport.

Regarding the implementation of manually driven or automated technical equipment, warehouses have already started implementing new solutions consisting primarily of self-contained robots that perform specific tasks without—or with minimal—communication or coordination with other systems. As a result, human intervention is still required for most of the current operations or fully relies on it in the event of a defect. The same principle applies to using forklifts to load and unload pallets into trailers. The main difference is that the human intervention happens occasionally in the first case, while in the latter, the human intervention is structural. In this context, the drive given by human operators is still central. Hence, labour must be considered as further operational costs, next to system implementation costs.

An exhaustive literature review is carried out to shed light on working practices addressed by academia when studying technologies and warehouse management systems. This overview points out how academia analysed the changes in working practices and technology changes in warehouse operations in the past and, thus, defines the gap in the literature regarding this topic. The literature review screens out peer-reviewed articles covering 1997–2022 in recognised academic database search engines (Scopus, Science Direct and Web of Science). The following keywords are used as search terms: “warehouse costs technology” accompanied with other terms like: “buffer”, “loading”, “unloading”, “transport”, “transportation” and “inventory management”. Content, relevance, and the use of at least a use case are the three criteria for screening the articles. A meticulous reading focusing on these studies' purpose, methodology and conclusions resulted in the retention of 37 relevant publications.

Table 1 below centralises the key outcomes of the literature review and indicates which and whether specific changes occur when implementing new logistics chain technologies involving warehouse operations. Moreover, a line is added to this overview table to highlight the differences of the current research compared with the work already carried out on introducing new technologies in warehousing operations.

Table 1 Operational cost elements for loading operations

Operational costs	Explanation
Employees cost	This cost relates to the average hourly wage of the operator handling the equipment used for unloading, preparation, checking or loading the cargo. These costs may vary depending on the technology used (as different technologies may require different skilled operators, e.g. when working with a high-tech system, a more expensive operator with a higher average hourly wage is employed)
Fuel/energy cost	This cost element relates to the fuel or energy consumption of the equipment used. For forklift trucks, an average hourly fuel consumption must be considered, while for equipment using electrical energy, this input must bear the average hourly energy consumption
Cost of faults (human error, scanning at loading operations)	This cost element relates to the frequency of errors per week. The type of errors covered by this element relates to the loading an incorrect pallet into a trailer due to a human error, incorrect scanning, etc. These types of costs are in principle eliminated when automated loading technologies are used. This cost element should not be confused with the cost of physical damage to pallets or equipment. These types of costs are included in a separate cost element
Cost of delay	This cost element refers to the average cost per month caused by delays in loading/preparing/unloading the cargo. Costs such as loss of revenue (e.g. due to delays), fines from customers, etc. should be included in this category
Cost of accidents	This input relates to the expected number of accidents per year that are caused during loading/preparing/unloading operations. This input has to be based on historical data
Cost of damage	This cost element relates to the value of the damage to loading units, equipment and/or goods caused by the loading technique used

Types of operational and technology cost	Year	Managing inventory	Moving the cargo internally	Loading	Unloading	Transporting	Manned operations	Unmanned operations	Technology cost
Authors									
Chaudhuri and Dayal (1997)	1997	X					X		
Gunasekaran et al. (1999)	1999	X	X				X		
Berg and Zijm (1999)	1999	X					X		X
Hwi Kim and Hwang (1999)	1999		X				X		
Ioannou and Sullivan (1999)	1999			X	X		X		
Rouwenhorst et al. (2000)	2000	X					X		
Takakuwa et al. (2000)	2000			X	X		X	X	X
Mason et al. (2003)	2003	X				X	X	X	
Liu et al. (2006)	2006	X	X				X	X	X
Ding et al. (2008)	2008	X	X				X	X	
Mallidis et al. (2012)	2012	X	X			X	X		
Karasek (2013)	2013		X				X		
Ding (2013)	2013	X	X				X	X	
Öztürkçü et al. (2014)	2014	X	X	X	X			X	

Types of operational and technology cost	Year	Managing inventory	Moving the cargo internally	Loading	Unloading	Transporting	Manned operations	Unmanned operations	Technology cost
Authors									
Allison (2014)	2014	X	X				X		
Sainathuni et al. (2014)	2014	X				X	X		
Davarzani and Norrman (2015)	2015	X	X				X	X	X
Manzini et al. (2015)	2015	X	X				X	X	
Goyal and Sharma (2016)	2016	X					X	X	X
Aro-Gordon and Gupta (2016)	2016	X					X		
Michał Kłodawski et al. (2017a, b)	2017	X					X	X	
Kłodawski et al. (2017a, b)	2017	X	X				X		
Oluwaseyi et al. (2017)	2017	X	X				X		X
Shepelev et al. (2018)	2018			X	X		X	X	
Andelković and Radosavljević (2018)	2018	X	X				X		
Kamali (2019)	2019		X				X	X	
Wang et al. (2020)	2020	X	X				X		
Hao et al. (2020)	2020	X					X		
Utama et al. (2020)	2020	X	X			X	X		
He et al. (2021)	2021		X					X	
Cano et al. (2021)	2021	X	X				X	X	
DeSutter and Gao (2021)	2021	X	X				X		
Lewczuk et al. (2021)	2021	X							
Küçükyavaş et al. (2021)	2021	X	X					X	X
Liu and Ma (2022)	2022					X	X		
Tokat et al. (2022)	2022		X	X			X		
Current research		X	X	X	X	X	X	X	X

The screening of these studies in Table 1 leads to the following key conclusions:

- No model seems to exist which investigates a complete set of changes (e.g. preparing the cargo, loading/unloading itself, transporting or managing inventory) brought by the automation of loading activities in the production environment.
- Most of the research initiatives investigate the changes brought by technologies on the management of inventories, linked with the impact on the production process or internal transport.
- It is also evident that the majority of the publications assess the use of manual labour in the logistics chain operations

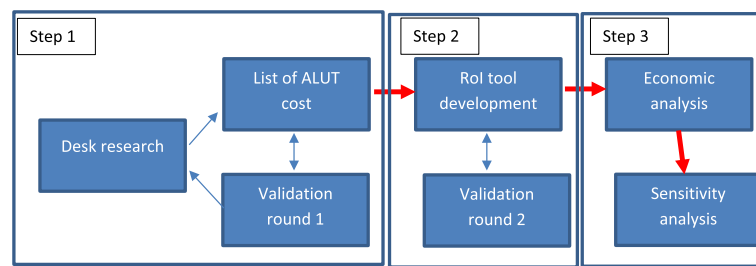


Fig. 1 Overview of the research approach

- Only a few publications consider the cost of introducing new technologies in the assessment of the case studies

The follow-up sections provide the research approach taken to determine a complete set of cost elements associated with the operational changes this type of automation introduces.

Research approach

This research follows a top-down approach that starts with identifying the issues when purchasing new technologies. Therefore, desk research and stakeholder interviews were conducted to determine the cost elements incurred at the purchase of ALUT. An RoI calculation tool was developed to follow up and use these outcomes. Finally, a scenario analysis was carried out to check the sensitivity of economic indicators when input elements change. These steps are presented in Fig. 1.

The initial steps of the research allow identifying the issues encountered by decision-makers when purchasing ALUT and pinpointing a comprehensive list of cost elements that need to be considered in the model.

The first step was carried out through an expert meeting and two follow-up meetings. The expert meeting was organised with seven representatives from companies representing: depots, warehouses, and distribution centres. These representatives hold functions like: Chief executive officer (CEO)s, project managers, operations managers, and consultancy representatives specialising in advisory services for ALUT purchase (see “Appendix 1”). The expert meeting lasted for 3 h and had the following structured approach. Firstly, a case study that implemented a new loading technology was presented, detailing the issues encountered. Secondly, an extensive list of types of cost generated in practice was presented from the experience of the consultant representative on which the group of industry representatives made amendments and additions. Based on this step, a final list of cost elements was defined. As a follow-up step of this expert meeting, extra desk research was carried out. To finalise the first step, two additional meetings were held to validate the final list of cost elements with two other operations managers at two warehouses (see Fig. 1, step 1).

A modular cost calculation tool was built with a consistent list of cost elements. This tool considers the cost elements and feedback received in the previous step. The tool’s

Table 2 Cost elements for purchase of loading/unloading technologies

Purchase costs	Explanation
Equipment cost (technology and/or forklifts)	These costs relate to the cost of the new device. It concerns therefore either forklifts or any of the ALUT systems
Project extra costs	This line adds up the extra project costs as there are: direct costs for the installation/delivery/set-up etc. of the device and the costs with setting-up the infrastructure needed to enable the equipment use
Cost from 3rd parties	This type of cost refers to the extra costs paid by third parties for custom-made equipment (e.g. cost of having trailers modified). In the context of this exercise, it was taken into account that these costs are incurred by third parties (e.g. road carriers), but they are passed on to the user of the technology (e.g. client/warehouse owner), through fees or higher service prices
Indirect cost	This field adds the indirect costs (e.g. costs to install/develop additional premium functionalities (by someone outside the company) or costs of parties monitoring the purchase process (from inside or outside the purchasing company, e.g. management of the construction)
Risk funds	This field indicates the total costs associated with the project risks (e.g. possible additional management/communication costs related to direct or indirect costs, if applicable) or emergencies (e.g. for unforeseen situations, operational interruption due to a technical problem, etc.)

outcome monetises the operational changes introduced by new loading technologies. It compares the cost generated by implementing and using each new ALUT with the cost of operating conventional forklifts. The tool and its results are validated in the second round of two expert meetings with a logistics expert and a professional in implementing automated loading technologies (see Fig. 1, step 2).

With the validated model, it is possible to make the calculations for the case study, along with the sensitivity analysis (see Fig. 1, step 3).

Costs elements and the RoI model of ALUT

The following sub-section presents the main cost categories identified in the initial research step.

Main cost categories for ALUT purchase

Two main categories of cost are identified, namely operational and purchase costs. Table 1 presents the list of operational cost elements, while Table 2 presents the list of purchase costs.

The lists of cost elements presented above are used to build a cost and RoI calculation model. The following section details the functional design of the calculation model.

The RoI calculation model

This section aims to describe how the cost and RoI model is developed. It provides an overview of the type of costs incurred by warehouses and depots when purchasing ALUT to replace forklifts. Loading equipment refers thus either to forklifts used at loading trucks or to technologies that have thus the goal of automating the loading/unloading operations.

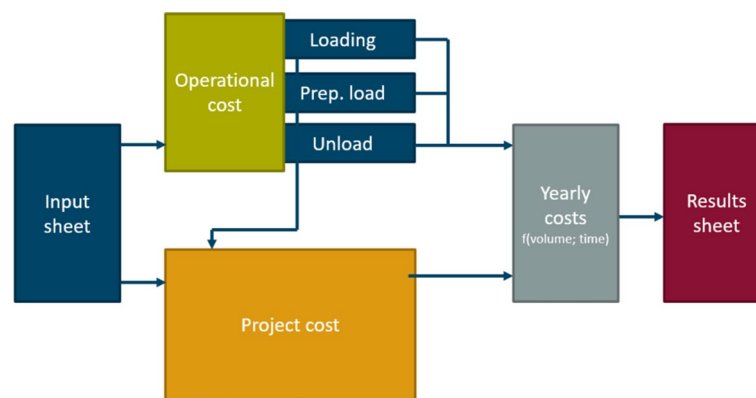


Fig. 2 Functional diagram of the cost calculation model

The tool explained in this paper follows the functional diagram presented in Fig. 2. Each main block is presented in the next sub-sections, where a detailed explanation is given about each element used in the calculation.

As shown in Fig. 2, a first input block serves to be filled in with general details about the warehouse or depot. This block collects key information for calculating operational and project costs later. Three 'operational cost calculation' blocks retrieve the required information from this input sheet. These three blocks are similar in structure and calculate, for each technology, the cost of loading, preparing the load (seen as the total operations done from when the cargo is taken up from the warehouse shelf and brought to the buffer zone for loading), and unloading the cargo. These results are used as input then to determine the yearly operational cost in the 'Yearly costs' block. In parallel, a 'Project cost' block calculates the project cost of each technology. This block retrieves as well key input from the 'Input sheet'. This block's results are also used later as input for the 'Yearly costs' calculation.

The last calculation block overviews the yearly costs generated by the implementation and use of each technology. The operational cost calculation is done as a function of forecasted volumes of pallets to be handled (yearly). The project cost is calculated based on the input from the previous blocks, considering periodic maintenance costs. The results of these calculations are then centralised in one main 'Results' block. This final block visualises the results concerning using ALUTs relative to forklifts. By following this structure, intermediary results can be also read and checked out from each block. Equally, this structure allows the user to check and slightly change, if necessary, the fixed variables used in the functional and project costs calculation.

This tool relies thus on input elements that are distinct per warehouse. The tool-user can change these elements according to their data, preferences, or pre-defined scenarios. The key input elements are referred to as primary input variables. The newly developed tool is further used to conduct an empirical analysis and build a case study. The characteristics of this case study are presented in the next section.

The novelty of this model is twofold: first, it considers the capital investment cost of equipment, and second, it calculates, in parallel, a completed set of operational costs generated when an ALUT is used. More specifically, it includes the extra cost caused by changes needed to adjacent operations to the loading itself, e.g. activities needed to

prepare the loads for the automatic handling equipment or activities required to unload the loads from the transport vehicles. This addition covers to a full extent the economic implications of purchasing and deploying automated loading/unloading equipment.

Loading and unloading technological solutions

This research brings three ALUT and the use of classic forklifts in economic analysis. The three technologies compared carry the following generic names: loading plate, transport belt and skate + system. The functional specifications and operational modes of each technology are key input elements in the model calculation, as well as the operational needs of a warehouse. Therefore, these specifications are presented in Fig. 3.

High-voluminous good flows with standardised morphology require repetitive operations during a classic loading and/or unloading process, which can be very time-consuming. For example, unloading a trailer using a forklift truck involves the repetitive entry and exit of the trailer, which slows down the loading and unloading process. Tackling this fragmented loading and unloading pattern is one of the strengths of the new ALUT, as shown in Fig. 3.

The table below shows the main specification of three loading and unloading technologies that can replace forklifts.

As seen in Table 3 above, each technology has its key specifications that determine how fast (or slow) the loading process is, what implementation costs are and which changes are needed to be introduced extra to the operational process that prepares or unloads the loads (pallets).

The “loading plate” principle comes into play where voluminous, difficult to manoeuvre goods should be loaded into a container or trailer. Loading through this system is characterised by a high frictional resistance at the contact between the loading plate and the load (pallets). This system requires that dedicated preparations are made, so that the load (pallets) are unanimously aligned on the loading plate. Moreover, upon retraction, the loading plate might cause slight shift of the initial set up of the pallets, which will generate slight fine tuning for a next machine to pick or raise pallets. This shift appears when any technology is used, yet the systems are foreseen to cope with this type of errors. The transport belt system requires as well that the trailer is well aligned with the loading conveyor system. Just before the loading, the controllers of both conveyor belts (outside and inside the trailer) connect according to a master–slave control principle. This operation consumes time. The latter is the operation that consumes the most time in practice, all the others can be neglected. After the preparatory work, the actual transfer of goods is no more than the simultaneous rotation of both conveyor belts, which causes the goods to move in or out a trailer. This system requires the trailer to be equipped with a dedicated conveyor belt, which is operated at loading and unloading processes. The working of a conveyor belt partly inspires the idea behind the loading/unloading principle using the Skate + system. The skate + system requires that “skates” are present over the entire length of the loading platform and spread across the width of the trailer. The rolling skates are embedded in U-profile platform that can be inflated so that the skates come in contact with the sliding loading plate. The inflated air pockets

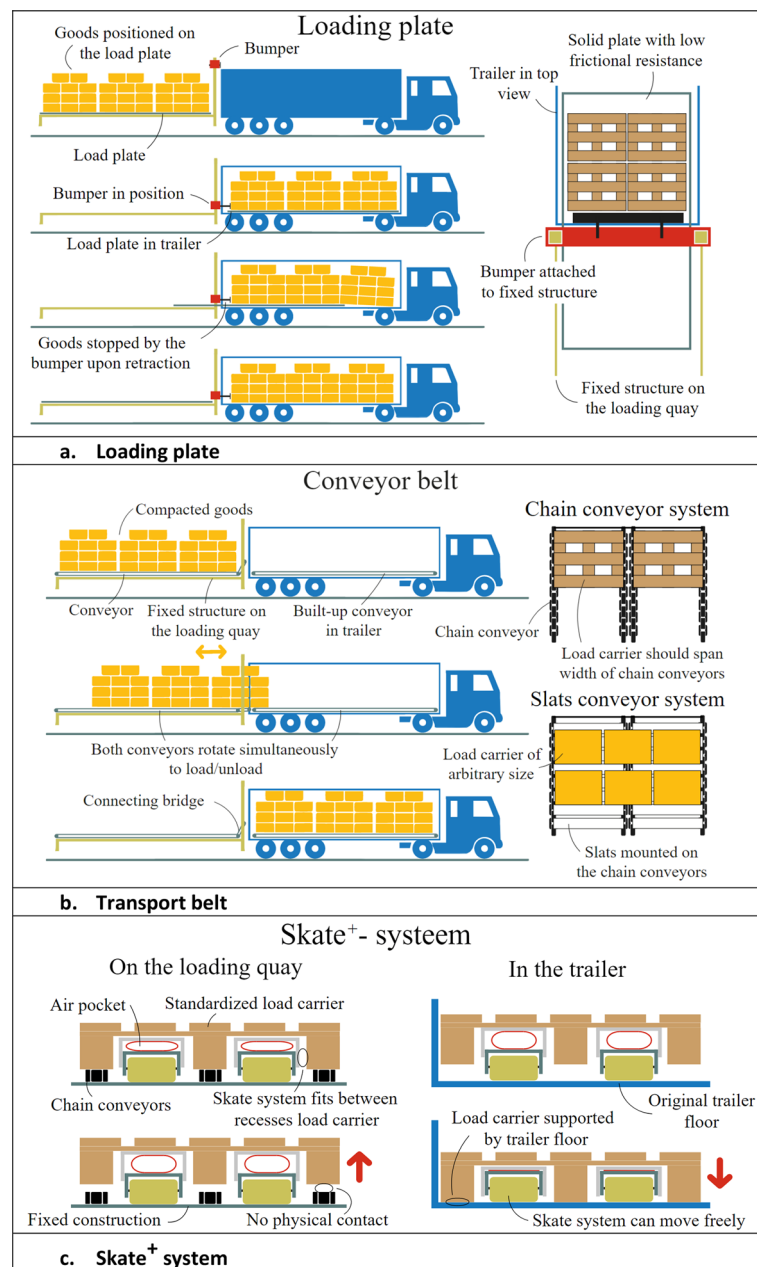


Fig. 3 Functional diagrams for the different ALUT

in the skate system, the upper U-profile, is pushed up to raise the load, meaning that the sliding U-profile platform will carry the load. This system implies complex operations for aligning the load (pallets), and inflating the loading U-profile from an external compressed air source.

The next session details the operational specifications and parameters type used in the further analysis.

Table 3 Key specification of ALUT used in the case study

Systems	Loading plate	Transport belt	Skate ⁺ system
Potential application use			
Loading	×	×	×
Unloading		×	×
Suitable for the following loading unit type			
Pallets	×	×	×
Cardon boxes	×	×	
Modifications needed to the trailer	×		
Loading/unloading speed	± 6 min/trailer	6 minuten/trailer	± 5 min/trailer
Maximum loading weight	± 30 ton	± 30 ton	± 30 ton
Key feature	Sliding plate with low mechanical resistance	Conveyor belt inside the trailer	Inflatable system inside the trailer
Main disadvantages	Fast loading of non-palletisable goods with non-standard dimensions It sets stress on the cargo during the sliding process and the trailers require in some cases additional investments The end-to-end (preparing the cargo-loading–unloading) process cannot be carried out in fully automatic mode	Loading and unloading of general goods Fully automatic loading system It requires additional investments to the trailers and regular maintenance as it consists of moving mechanical parts The trailers need to be well aligned with the loading dock	Loading and unloading without any modification to the trailer It is mandatory that the pallets have no defects High initial investment The trailers need to be well aligned with the loading dock

Case study

The model always retains the use of forklift trucks as a reference scenario and relates the costs of other technologies to it. The tool makes a difference between the cumulated costs of using the new ALUT and the cost of using forklifts.

Main results

The following results are obtained referring to an average-size warehouse. The operational characteristics of this warehouse and the framework of this empirical analysis are presented in “Appendix 2”. Moreover, the cost elements generated by each technology purchase are shown in “Appendix 3”.

Purchase costs

This section gives a more detailed approach on the purchase cost of ALUT. Figure 3 compares the purchase costs between the analysed technologies, while Fig. 4 shows their cost structure.

From the Fig. 3 it can be concluded that the use of forklifts generates the lowest purchase cost and appears the best technology to be chosen based on these criteria alone. The loading plate and the transport belt technologies generate comparable purchase cost, though these costs are higher than the use of forklifts. From Fig. 3 can be also observed that the Skate+system generates a relatively high purchase cost, almost 4

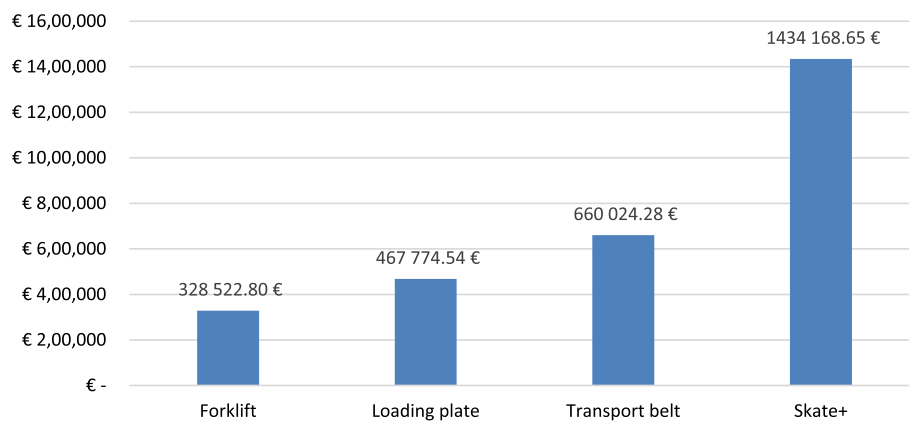


Fig. 4 Purchase cost for each technology type

times higher than the use of forklifts making this technology unattractive to punchers in a first place.¹ Triggered by these results, Fig. 4 gives more details regarding the structure of purchase costs for loading/unloading technologies.

Figure 4 shows that the main cost component for loading technologies is the acquisition cost of the equipment. Besides this cost, other costs are also incurred. The purchase of forklifts is quite straightforward and does not generate other type of costs than risks. The same type of costs is also incurred if other technologies are purchased. It is noticeable that the Loading plate and Transport belt generate noticeable indirect costs. These costs are usually associated with the need for extra adaptations to the warehouse to enable this technology's use. Moreover, the purchase of the Transport belt carries a relatively high cost to 3rd parties. This cost is generated by the custom adaptations necessary to be made to trailers. This type of cost is expected to be covered by the warehouse by either directly covering this custom adaptation work or being required to pay relatively higher transport fees to road carriers that own these custom trailers. For the Skate+ technology, the extra cost besides the equipment's acquisition is relatively low.

Triggered by these results, a further step is taken in this research and an in-depth operational cost analysis is made. The following section details these results and analyses the results further from this perspective.

Operational cost

This section details the results regarding the operation cost generated by each technology. Figure 5 compares the average cost per pallet for the handling operations. This figure splits these costs according to the loading operation, and the operations taken to prepare and unload the load. In addition, Fig. 6 shows results with concerning the cost structure for using each of the analysed technologies. These results are obtained based on estimations provided in the specifications sheets of each technology type.

Figure 5 visualises a comparison between the operational costs generated by each technology. This figure shows that using the transport belt as automatic loading/

¹ These results are compared with having 6 forklifts in use.

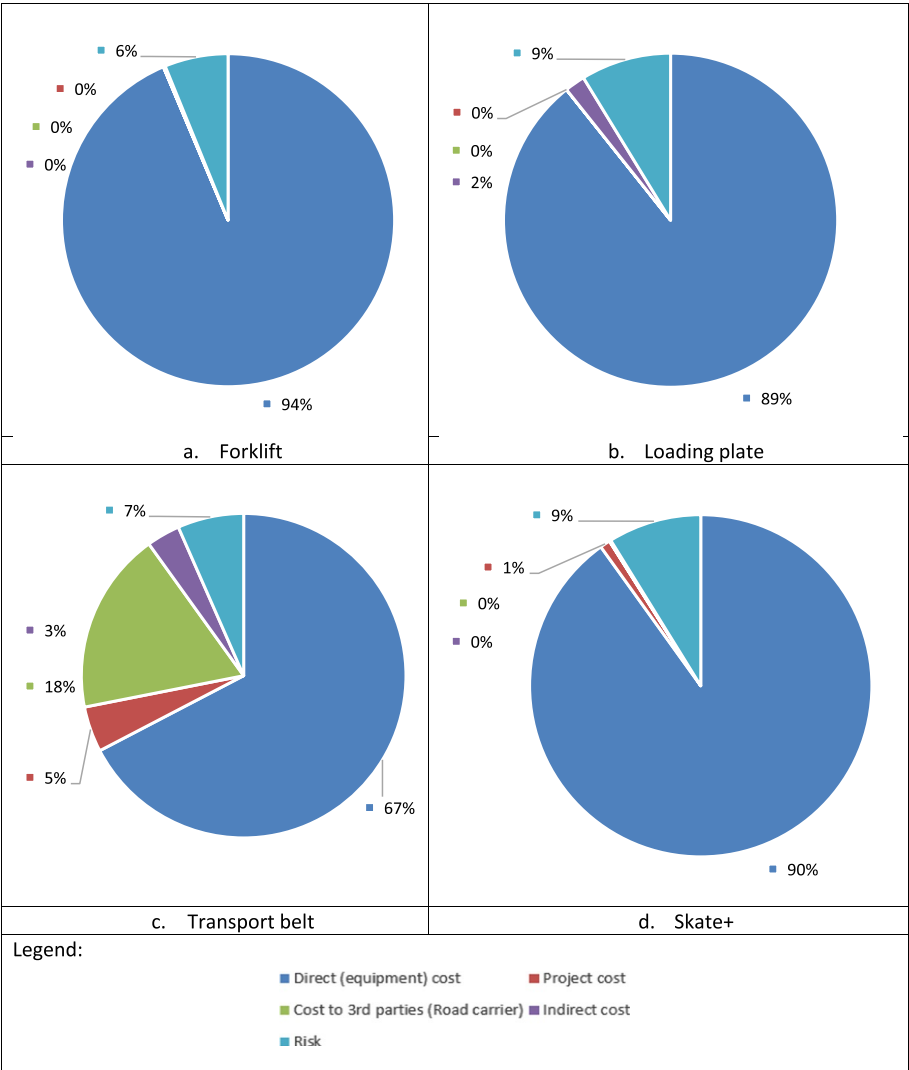


Fig. 5 Purchase cost structure

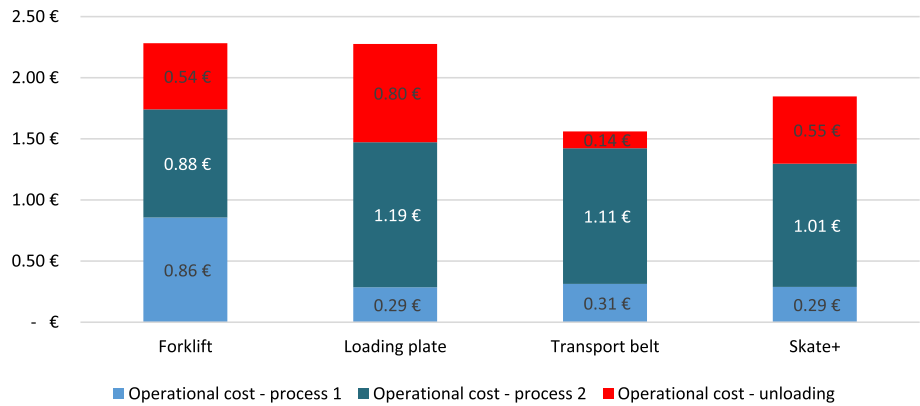


Fig. 6 Operational cost generated by each technology

unloading generates the lowest operational cost. The cost of loading is around 0.14 EUR/pallet when this technology is used, while the other technologies generate higher average costs. This results from the possibility enabled by this technology to shift the entire load of pallets into the truck in one move, during a relative short amount of time and with the involvement of one operator. The use of the Skate + system and the forklift, generate equal operational costs, but both are higher than the use of the transport belt. This results from a relative longer amount of time necessary to retract the loading boards for the Skate + system from beneath the pallets or to handle pallets one-by-one when forklifts are in use for the unloading operations. The Loading plate technology generates the highest operational loading cost. In this case, this operation is done at a low speed. The low speed is necessary to drop the pallets on the trailer's bed without extra damages.

Looking at the operational cost of preparing the load, it is observed that the use of forklifts generates the lowest cost. The activities taken to prepare the load are longer when other technologies are used. If automatic loading technologies are in use, the pallets need to be fixed on either a loading plate or skates, which require sometime slight adjustments. The results regarding the unloading operation show that the loading plate generates the lowest average cost. When this technology is in use, the pallets are finely aligned in the trailer enabling an unloading process that is more accurate and faster. The use of forklift generates the highest costs here. This activity requires the involvement of forklift operators that handle each pallet individually from the position inside the trailer to the unloading bay, which are costly.

Based on these results, it is obvious that using the transport belt generates the lowest operation cost. Triggered by these results a further look is taken at the cost structure for each technology. Figure 6 present the results regarding the percentage of each type of cost that composes the operational cost.

Figure 6 details the cost structure and the components of the operation cost. In this figure, it is observed that employee cost is the main cost category for each technology. The use of the Loading plate and the Skate + systems generated the highest cost associated with fuel or energy. These types of technologies rely on skidding the loading plates or moving components, which results in relative higher energy use. The use of forklifts also generates costs associated with faults or delays. The manual and individual handling of pallets with forklifts generate these types of costs. The automatic loading/unloading technologies benefit from advanced scanning systems that eliminate this type of costs. The cost associated with accidents are present in the same percentage across the technologies. It is also noticed that the damage costs are higher in case a Transport belt is used. The use of Transport belt sets relative higher mechanical stress on the loading units, sometimes leading to their failure.

The following section details the results concerning cost calculation when both operational and purchase costs are considered.

Total cost (operational and purchase costs)

The individual results regarding the operational and purchase type of costs indicate different technology as the best solution for loading/unloading operations. Decision-makers giving the most importance to one or another criterion reach thus to different

results. This section makes an extra step in this analysis and, using the calculation tool developed, provides other effects concerning the total costs generated by each technology after 10 years. This calculation incorporates the cost associated with the operation and purchase of ALUT. Figure 7 details the percentages of these costs that contribute to the total costs. Later, Fig. 8 compares the total prices generated by each ALUT after an exploitation time of 10 years.

As seen in Fig. 7 above, the Skate + system carries the highest share of purchase costs in their cost structure. This technology's purchase cost was shown as the highest in the section above. The loading plate and transport belt systems appear to have similar cost structures. Yet, the use of forklifts has the lowest percentage of the purchase cost in its cost structure. Figure 8 compares the ALUT analysed from the perspective of absolute total costs.

Figure 8 shows that the transport belt is the most economically advantageous solution for loading/unloading operations, while the Skate + system is the most expensive. The use of Loading plate and Forklifts generate higher total costs than the use of transport belt after 10 years. The operating cost for these technologies is expected to be higher due to the involvement of human operators. The purchase of a forklift, although cheaper, it generates higher operational costs for the same reason. The graph in Fig. 9 shows the cost evolution for these analysed technologies.

Figure 10 shows the cumulated cost for each analysed technology over a period of 10 years. As seen in this figure, the cost of using forklifts is low in the first year. The Loading plate, Transport belt, and Skate + systems generate higher purchase costs and thus create higher total costs in the first period of operation. After 10 years, the cost of purchasing forklifts adds up with the cost of operating them, resulting in a much higher total cost generated by this technology. The cost of using a Transport belt is the lowest after 10 years of exploitation, followed by the cost of using a Loading plate. The cost of using the Skate + technology is always higher than the cost of purchasing and operating any other technology. Table 4 below provides further results assuming using forklifts as reference technology. These results show each technology's return on investment (RoI) and the break-even period.

According to the results in Table 5, it can be observed that the Transport belt technology offers the highest RoI. After 10 years, using a Transport belt generates costs that are 11% lower than forklifts. The same conclusion is also made when loading plates are in use, which generates costs that are 4% lower. As could be anticipated from previous results, the Skate + technology does not lead to a positive RoI. Moreover, by using the Transport belt, the users can reach break-even after 3 years, 1 month, 3 years, and 8 months respectively, in case of choosing to purchase the Loading plate technology.

The results presented above are valid for the initial input of data valid for a mid-size warehouse. However, these input data can vary. The following section presents a scenario analysis for variations of the key input data.

Scenarios analysis regarding the RoI

The key input data could change, therefore the results of an analysis. This section uses the input received in the validation meeting and varies key input data to show further

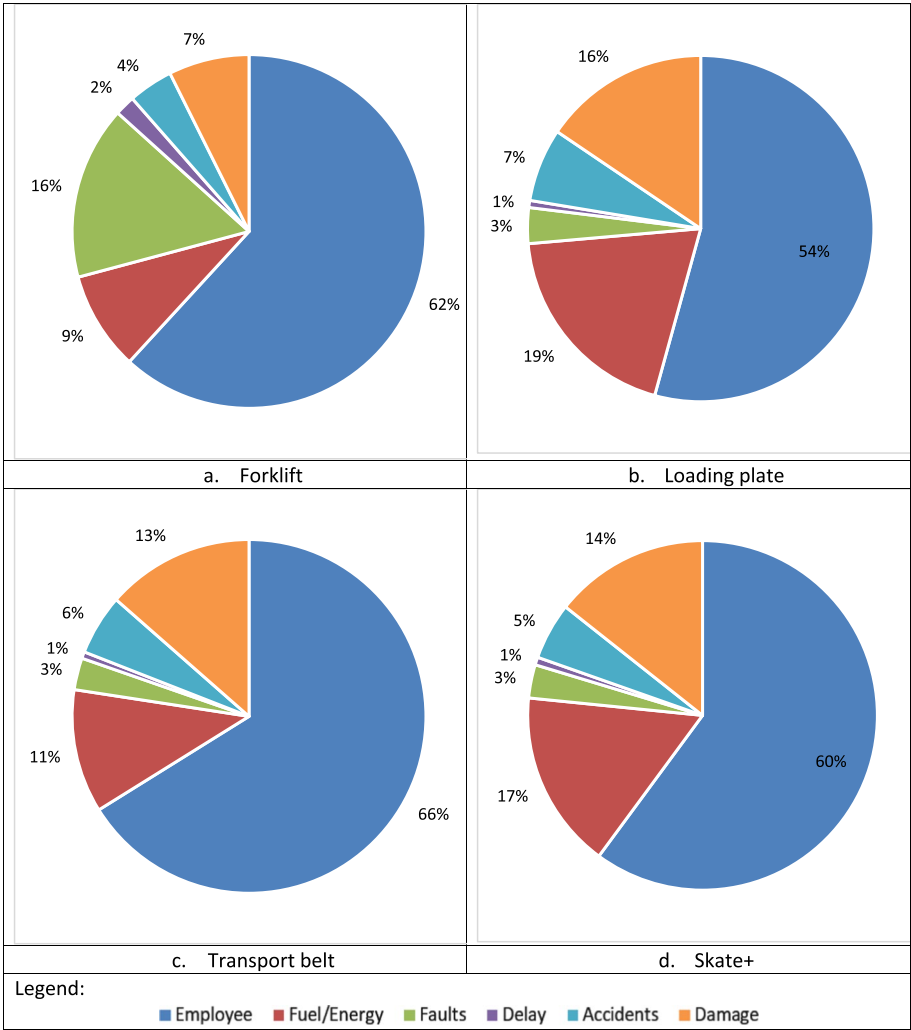


Fig. 7 Cost structure of the operational costs

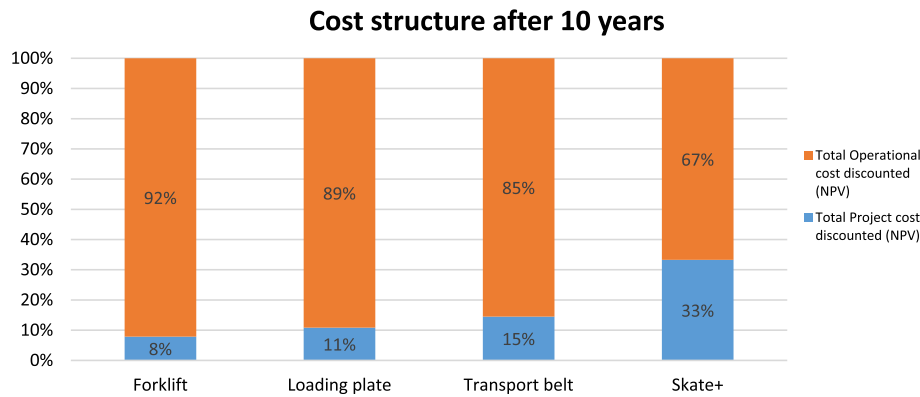


Fig. 8 Total cost structure (purchase and operational) for implementing each technology

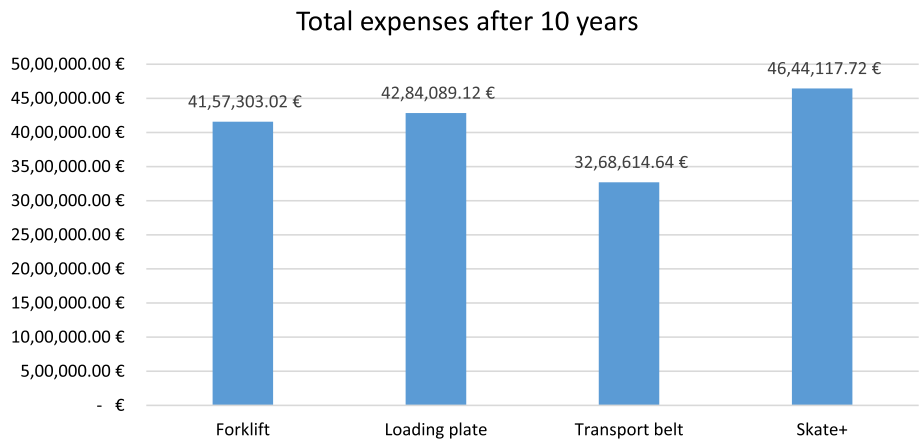


Fig. 9 Total cost generated by each technology after a period of 10 years

Table 4 Results with regard to the RoI and break-even period

	Measurement unit	Loading plate	Transport belt	Skate +
Return on investment after 10 years,	[%]	4%	11%	No positive ROI
Estimated break-even period	[years]	3 years and 8 months	3 years and 1 month	No break-even point reached

results. Results from the perspective of RoI and the break-even period are provided again from the perspective of each technology. These results are relative to the conventional case of using forklifts.

The first scenario tested concerns an increase in the number of pallets a warehouse handles. This scenario tests the effect of a yearly increase of 5% in the number of pallets needed to be handled. This Increase determines that the transport band generates a

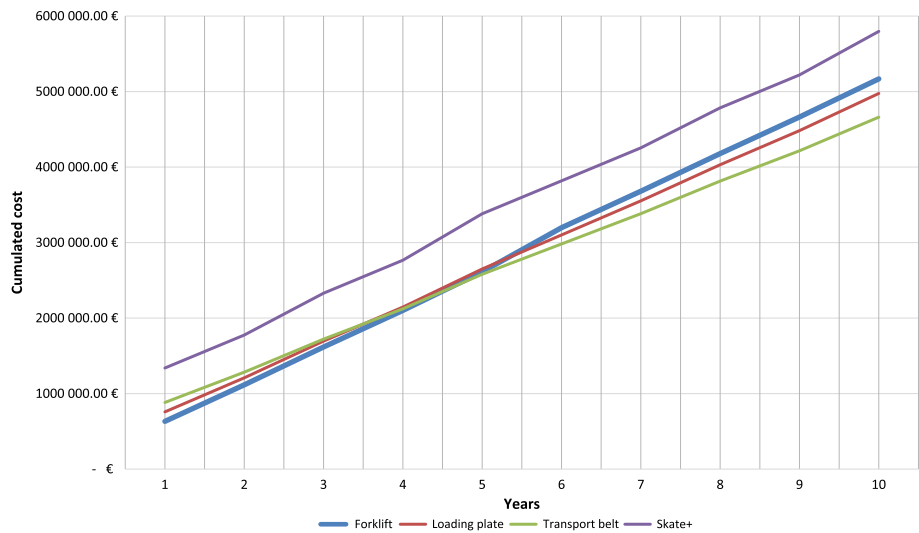


Fig. 10 Evolution of the cumulated cost for each technology

Table 5 Results associated with changes in the input elements

	Loading plate	Transport belt	Skate +
<i>Scenario A (Increase of 5% of volumes every year)</i>			
Return on investment after 10 years	5%	13%	No positive ROI
Estimated break-even period	3 years and 2 months	2 years and 8 months	No break-even point reached
<i>Scenario B (Increase of 15% of labour cost)</i>			
Return on investment after 10 years	13%	22%	No positive ROI
Estimated break-even period	1 year and 3 months	1 years and 9 months	No positive ROI
<i>Scenario C (increase the technology risk from 0 to 15%)</i>			
Return on investment after 10 years	3%	10%	No positive ROI
Estimated break-even period	4 years and 2 months	3 years and 4 months	No break-even point reached
<i>Scenario D (Using a 100% loading degree of trucks)</i>			
Return on investment after 10 years	4%	41%	16%
Estimated break-even period	3 years and 8 months	5 months	2 years and 4 months

13% ROI and reaches the break-even period after 2 years and 8 months. The increase in the volume of pallets impacts the operational cost of pallet handling. A higher volume of pallets generates a lower average operational cost. It is essential to mention that a 5% increase in the volumes handled does not imply an increase in purchase costs (purchase of extra equipment). The second scenario considers a 15% of labour cost. This increase generates as well higher operational costs. Therefore, the use of forklifts is highly impacted as every handling or pallet move implies an employee's involvement. This type of cost increase generates higher operational costs; therefore, automatic loading technologies provide a higher RoI and faster break-even period. The third scenario introduces an increase of risks for new technologies. This risk is quantified by considering an equivalent to 15% of the purchase value of new equipment that might be spent during the operating period. This increase results in lower RoI and a longer break-even period for ALUTs.

Yet, the ALUTs are still providing the best economic results (concerning the RoI and break-even) after 10 years of operation relative to the use of forklifts. The last scenario simulates using 100% of trucks' loading capacity (increased from 80% as given as average in the initial validation meetings). This type of operational change positively affects the results obtained for the ALUTs. The RoI proves to be much higher in case of using the transport belt technology to load trucks at their full capacity. The average loading cost is lowered. Using 100% of the trucks' capacity determines that the costs for using this technology are break evened with the cost of using forklifts after 5 months. The increase in the use of the entire truck's capacity does not show any significant changes in the economic indicators for the loading plate. If the trucks are loaded at 100% of their capacity, it is observed that Skate+ technology can be considered as an alternative approach that generates lower costs than the use of forklifts. In this case, the RoI of using Skate+ system is 16%, and the costs of using forklifts are equalled after 2 years and 4 months.

The following section provides the main conclusions of this research and recommendation for the purchase of automated loading technologies from an economics point of view.

Conclusions

This paper investigates whether the use of new loading and unloading technologies brings economic benefits when the complete set of costs regarding adjacent operations (like cost of activity for preparing the load or un-loading) are considered. This investigation is carried out by developing a tool that calculates the cost, RoI and break-even period of ALUTs. This tool is designed to be used by warehouses, depots, etc., managers, researchers, and academia that have an overview of the operational characteristics of warehouses and are investigating the decision on whether to purchase new innovative automatic loading/unloading equipment. This tool enables them to input operational data and check the variation of several economic indicators like purchasing automatic loading/unloading technologies.

A literature review of papers studying technologies used in handling warehouse operations shows the following shortcomings. Firstly, the focus of up-to-date papers is mostly set on the loading capacity of new equipment. This leaves unaddressed the capacity of equipment or activities carried out for preparing or unloading the loads. Secondly, these papers show that there are advancements in technologies that store, sort or transport cargo, but economic analyses look at the purchase process cost or the operational cost individually. No model integrates both purchase and operational cost to give a comprehensive economic overview to the decision body. Thirdly, applications to calculate warehouse-specific operational cost or cost to purchase certain equipment, do not offer functionalities to benchmark new technologies to as-it-is scenario (regarding the total costs generated by new equipment). Lastly, the decision-makers would like to look also at the broader operational impact (e.g., the entire chain of activities carried out) when certain technologies are introduced. For example, in case of introducing automated loading technologies that change the process of preparing the load, it is required to know which extra costs this change generates. More concretely, by making changes in the handling capacity of the systems in an industrial production line, each element of the production line should be adapted. The systems that depend on each other require adaptations or extra detailed checks to prepare the loads. Similarly, the unloading operations suffer changes as well. Therefore, this paper makes further steps in theory, including the above shortcomings in one RoI calculation tool.

This paper identifies the main categories of costs necessary to be considered in purchasing automatic loading/unloading technologies. There are two main categories of costs operational cost and the cost of purchasing the equipment. These two main cost categories of costs can be further split as follows. Operational costs are cost incurred with employees, fuel, damages, faults, and accidents. Purchase cost, beside the equipment acquisition cost, carry also other types of costs such as: project planning cost, cost generated through third parties (that also need to make investments) and establishing a risk account. These categories of costs represent a comprehensive set of cost elements

that need to be considered when comparing the economics effects of introducing new ALUT.

After identifying and validating these elements, this paper pursues the development of a calculation model that provides the cost, RoI and break-even period of implementing new technologies. This model individually calculates all the sub-cost components and integrates them into comprehensive cost calculations.

The numerical calculation uses input values from an average-size warehouse. Results are calculated for three automatic loading technologies: loading plate, transport belt, and a Skate+ system. The results show that, by looking only at the average operational cost for handling one pallet, the use of the transport belt technology gives the best economic results. This technological solution reduces mainly the costs with the employees and energy use. Yet, using the purchase costs as a benchmark, using forklifts is the solution that brings the least cost. The total operational and purchase costs are brought together in one economic indicator and are used to further calculate, after 10 years, which solution offers the lowest expenses. The calculation shows that the transport belt remains the option with the lowest cost, providing the best return on investment regarding using forklifts. Operational costs mainly dominate the cost structure of using this type of equipment.

As a next analysis step, this paper uses the newly developed RoI calculation tool to provide more insights regarding the sensitivity of the RoI and break-even period of each technology to variations of key input elements. Several analysis scenarios are thus defined, for example, regarding the variation of the number of pallets handled by a warehouse, labour cost, technology risk and the use of the loading capacity of trailers as follows. The results show that an increase in the volume of pallets being handled will generate higher RoI for ALUT. Similar results are observed also if the labour cost rises, as operational costs are mostly depended on labour costs. The results show that by quantifying technology risks, the new ALUT bring lower RoI. The scenario analysis also shows that the purchase decision of automatic loading technologies depends not only on technical specifications that each technology carries, but also on the external factors such as the practice of using the full trucks' capacity. As show in the last analysed scenario, the better use of trucks' loading capacity can generate better economics results for ALUTs.

The development of the RoI calculation tool shows that a significant number of variables need to be considered when implementing new ALUTs. With this development, sector representatives and academia benefit from a comprehensive cost calculation tool.

Regardless the achievements mentioned above, this research presents the following limitation. Although the method is explained in detail and is replicable to other case studies, the results obtained from the empirical analysis are valid for the input data presented in the empirical computation sub-section. Hence, depending on the characteristics and activity of the logistics chain adopter, the RoI might be achieved after a different period or a different total expense. As such, company-specific data is required for the actual scientifically correct calculation, whereas average figures are recommended only for benchmarking purposes. A further expansion on the model presented would be to calculate the costs of each technology as a function of flow size and then determine at which volumes technologies such as Skate+ become financially attractive.

Appendix 1: List of participants expert meetings

Expert	Function	Company
Stefaan Van Driessche	Manager european distribution centre	Barry Callebaut
Wannes Van Rysselberghe	Logistics manager global distribution center	Barry Callebaut
Marlies Adamczyk	Supply chain Innovation manager	H. Essers
René Cremers	Responsible for automation projects	H. Essers
Jan De Winter	Distribution manager	Ontex
Denise Sweelssen	Supply chain director	Stelrad Radiator Group
Ruud Meijs	Warehouse manager	Stelrad Radiator Group
Marjan Gerken	Warehouse project engineer	Scania Parts Logistics
Gitte Daelemans	Logistics engineer	Yusen Logistics
Luc Rooms	Senior logistics engineer	Yusen Logistics
Dirk Ceulemans	Project manager warehousing	Yusen Logistics
Katleen Crauwels	Deputy general manager Antwerp logistics campus	Yusen Logistics
Mario Derycke	Advisor automatic loading technologies	MDR consulting

Appendix 2: Particular case data

Input element	Measurement unit	Potential variation	Value used in the main calculation
Total pallets per day	[Pallets/day]		650
Estimated Increase in total pallets per year	[%]		0
Length of the working shift	[Hours]		8
Truck average load	[Pallets]		33
Average loading degree	[%]		80%
Average waiting time (unproductive time within a loading cycle)	[Minutes]		15
Average hourly cost employee	EUR/hour	32–52	35
Technology risk	%	0–15%	0

Appendix 3: Case study cost parameters (input data)

Operational elements input Warehouse		Unit
Total pallets day	650	Per day
Opening days week	5	Days
Weeks in a month	4.3	Weeks in a month
Increase in total pallets per year	0%	%
Working shift	8	Hours per day
Truck average load	27	Pallets
Average waiting time	15	Minutes

Operational costs input					Unit
Overview	Forklift	Loading plate	Transport belt	Skate +	
Loading time	30	9	12	11	Seconds/pallet
Preparing the load time	75	90	90	90	Seconds/pallet
Unloading time	45	60	9	48	Seconds/pallet
Average hourly cost employee	37.00 €	42.00 €	39.00 €	35.00 €	Euro/hour
Project costs input					Unit
	Forklift	Loading plate	Transport belt	Skate +	
Equipment cost	22,500.00 €	160,000.00 €	100,000.00 €	400,000.00 €	Euro/piece

Abbreviations

AGV	Automated guided vehicles
ALUT	Automated loading/unloading technologies
CEO	Chief executive officer
Rol	Return on investment

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Author contributions

Conception: VC, EvH, TV; Design of the work: VC, EvH, TV; Data acquisition, analysis: VC, DC; Interpretation of data: VC, DC, EvH, SD, TV; The creation of new software used in the work: VC; Drafted the work: VC, DC; Revised the work: VC, DC, EvH, SD, TV; All authors read and approved the final manuscript. All authors have agreed both to be personally accountable for the author's own contributions. All authors read and approved the final manuscript.

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Availability of data and materials

The data based on which findings and conclusions were made is collected by the authors of this paper through direct interviews with representatives of supply chain stakeholders. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

The authors declare that they have no competing interests.

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