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Bachelor Assignment Industrial Engineering & Management

Warehousing trends and innovations: best practice

HEINEKEN

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Preface

This thesis wraps three years of Industrial Engineering and Management study at the University of Twente, in the Netherlands. It is during an internship of ten weeks at Heineken Netherlands, that this assignment has been brought to completion.

I am grateful for the flawless support that I received from Eric Kogeler, my supervisor at Heineken. He helped me with his weekly attendance to answer my question and keep track of the continuity of the project, but also connected me to the right people at the right time. I also want to thank everyone at Heineken that contributed in any way to this project.

Then, I also want to thank Breno Alves Beirigo for being my first supervisor. The feedback I was able to receive from him was always very insightful, and he always helped me to find a way out of the challenges that occurred during this thesis. I also want to thank Lin Xie for being my second supervisor.

Finally, I would like to also thank my friends, family, and boyfriend for their unequaled support during this thesis. Their encouragement has been essential and helped me through the difficult times.

Kind regards,

Sarah Aussaresse

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Management summary

Heineken, founded by Gerard Adriaan Heineken in Amsterdam in 1864, prioritized beer quality and family ownership. The company expanded to Rotterdam in 1973, gaining a strategic advantage in the ports. Today, Heineken is a multinational corporation with more than a hundred thirty breweries worldwide, employing over 85,000 people in more than seventy countries. With a net revenue of €28,694 million in 2022, Heineken operates in the FMCG industry, offering a variety of beer, cider, and soft drinks globally. They have over three-hundred brands available in more than a hundred ninety countries, catering to diverse consumer preferences.

Continuous improvement is a fundamental aspect of Heineken's work culture, driving employee performance and contributing to the company's success. The warehousing department is undergoing various transformations, leading to improvements in processes at different levels. Heineken actively seeks growth opportunities and aims to enhance efficiency in its warehouses. Technological advancements enable ongoing improvements through the introduction of new warehousing solutions. As the warehousing industry constantly evolves with new trends and innovations, it is crucial for Heineken to remain aware and receptive to change, constantly exploring new ideas and solutions. Staying competitive is essential for all companies, as it ensures customer satisfaction, fosters growth, and maintains credibility within the industry. Therefore, the aim of this thesis is to provide Heineken with more insight into warehouse trends and innovations to improve the efficiency of specific processes in the warehouse. Thus, the research question addressed in this thesis is:

"How can warehousing trends and innovations improve the performance of Heineken's processes in Europe?"

This thesis focuses on identifying trends in warehouse processes in Europe, specifically concerning warehouse equipment. The study excludes aspects related to warehouse layouts, such as sizing, structure, and department layout. Warehouses located in high-wage Western European countries are investigated in this thesis, as labor costs significantly impact expenses, and therefore warehouse efficiency.

To understand how the company measures its performance, Heineken's KPIs are analyzed. These KPIs are categorized into four groups: cost, productivity & utilization, quality, and time. The company has a total of forty-nine listed KPIs, with ten being mandatory and the remaining optional. While all categories of KPIs (cost, productivity & utilization, quality, and time) are theoretically important, the study found that productivity & utilization KPIs were the most prevalent. The case studies also revealed a shift in the industry's focus from cost reduction to improving customer satisfaction, highlighting the importance of quality. Heineken's evaluation of KPIs primarily emphasizes productivity & utilization but also considers the other categories. The presence of a mandatory KPI related to warehouse safety demonstrates the company's commitment to employee well-being. However, the evaluation suggests a lack of mandatory KPIs specifically addressing the quality of warehouse operations in logistics.

In Heineken's European warehouses, labor cost is a significant expense, and it was found to particularly be the case in the internal transport process. However, without reaching out to the individual OpCos, detailed information about this process was lacking. Therefore, the focus was on selecting a stable process that could adapt to changes. The chosen process involves transporting and scanning pallets. Three trends and innovations in material handling methods were researched: Automated Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs), and smart conveyors. For scanning methods, the technologies explored were automatic barcode scanners, Radio Frequency Identification (RFID) tags, and image recognition cameras. All the methods discovered were aimed at automation and unmanned operations.

When evaluating innovations, the literature suggests considering criteria such as fit, impact, and financial value to the company. Fit assesses whether the technology aligns with the specific process under consideration. Impact considers how the innovation will affect factors like quality, speed, dependability, flexibility, and cost. Financial value takes into account the payback period resulting from the technology investment. After investigation, certain potential solutions were found to be unsuitable for Heineken's warehouse process. Among material handling systems, only AGVs were deemed suitable for implementation; and regarding scanning methods, image recognition cameras emerged as a game-changing technology.

To conclude, a discussion containing limitations, validity, and reliability statements about the research is made. With that, conclusions, recommendations, and ideas for future research can also be found.

The most important recommendations are as follows:

- Review KPIs trends to be aware of industrial shifts when they happen. Research valuable quality KPIs for Heineken's vision.
- Get in contact with AGVs suppliers, and consider their applications in warehouses.
- The utilization of image recognition appears to be an exceedingly advantageous advancement. It is crucial to give careful thought to incorporating it in order to enhance operational efficiency.

Contents

List of acronyms

AGV Automated Guided Vehicle

AI Artificial Intelligence

AMR Autonomous Mobile Robot

BCS Business Comparison System

FMCG Fast-Moving Consumer Goods

FP Finished Product

FTE Full Time Equivalent

IoT Internet of Things

KPI Key Performance Indicator

L&D Learning and Development

LSP Logistics Service Provider

OpCo Operating Company

OTIF On Time In Full

PPI Process Performance Indicator

R&PMs Raw and Packaging Material

RFID Radio Frequency Identification

RPMs Returnable Packaging Material

SKU Stock Keeping Units

TRT Truck Residence Time

WMS Warehouse Management System

1 Introduction

This section is composed of a description of the company, followed by a characterization of the problem composed of the action problem, problem identification, core problem, and research motivation. Finally, the research design of this thesis is explained, and the limitations and deliverables are stated as well.

1.1 Company description

As Gerard Adriaan Heineken started his small family brewery in the heart of Amsterdam, what mattered the most was for his business to remain in the family, where the quality of the beer would always go first [1]. The story began in 1864 at the Haystack Brewery in the center of the capital. This one got rebuilt near the waterside where the exportation of finished goods and the reception of raw materials would be easier. Soon Heineken decided to expand, and it is without a surprise that he built his second brewery in 1973, the Rotterdam Brewery. This done, Heineken was present in the two biggest ports of the country, which gave him a serious advantage. From there on, Heineken multiplied awards and honors that contributed to the company's success in the world [2].

Today, more than 150 years later, Heineken is a huge multinational that counts more than 130 breweries in Europe and multiple others over the world. In 2022, the company employs over 85,000 people in more than 70 countries all over the world and had a net revenue of €28,694 million [3]. Heineken's products are part of the Fast Moving Consumer Goods (FMCG) industry. FMCG products, also called consumer packaged goods, are rather low-priced products that have a short shelf life and that consequently sell relatively quickly [4].

Heineken is customer-centered, and their focus is to innovate and to allow its beverages to go beyond the basics of beer. Accordingly to this principle, they produce beer but also cider and soft drinks with diverse recipes, alcoholic but also non-alcoholic versions, that vary from the simple bitter taste of beer to more flavored and sweet options. Heineken owns over 300 brands that are available in more than 190 countries. These varieties are divided between international brands and more local specialties, which ensure to meet consumer expectations [5].

1.2 The problem

1.2.1 Action problem

At Heineken, warehouse performance is essential, and finding new ways to improve it is a daily research topic. The "winning theory" of Heineken, the Green Diamond, which represents the company's objectives and ambitions, frames this research. The four pillars of this theory are:

- Growth
- Profitability
- Capital efficiency
- Sustainability & responsibility

Improving warehouse performance often means following market trends in the same industry to discover new methods and innovative solutions. Supporting the first driver of its strategy (growth), Heineken chose to focus on innovations [6], which refers directly to market trends. In line with this quest for improvement, this thesis aims to answer the following research question:

"How can warehousing trends and innovations improve the performance of Heineken's processes in Europe?"

The action problem resulting from this research question is:

"The growth options alongside warehousing trends are unidentified"

Norm and reality

By definition, an action problem is when there is a gap between norm and reality [7]. The norm is for Heineken to keep in line with its goals. This would mean that the company should constantly know what are the principal warehousing trends that could potentially improve its warehouse performance. However this deviates from reality, and a gap can be observed where Heineken is not completely keeping track of warehousing trends.

1.2.2 Problem identification

At Heineken, continuous improvement is a constant process that paces employees' working lives. This perpetual amelioration is a norm for managerial teams and is largely participating in the company's success. In warehousing, transformations of different types are taking place, leading processes to improve at various levels. Heineken is in a quest for growth opportunities and efficiency improvement in their warehouses. The performance of a warehouse can be continually further improved due to technological advances that generally result in new warehousing solutions. The performance of a constantly changing milieu is never optimal, which means that it can always be improved. The challenge is to stay aware of that and to be receptive to change since new ideas and solutions are constantly being released. Indeed, the warehousing industry is in a constant evolution paced by new trends and innovations.

The necessity to stay competitive is a must for all companies. Indeed, by staying competitive, companies also commit to customer satisfaction and focus on growth. Moreover, it is also essential for companies to keep track of trends in their industry in order to be relevant and credible when compared to other firms in the same business.

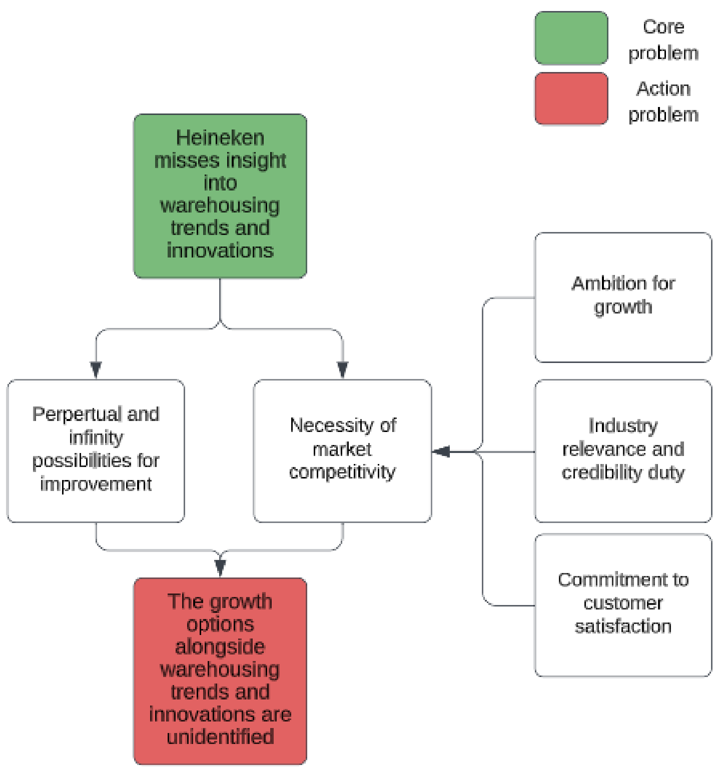

Figure 1: Overview of the problem cluster

1.2.3 Core problem

As explained previously, for Heineken, improving warehouse performance is always interesting. Nonetheless, to make the right improvement choices it is important to have insight on the different options. The company indicated its interest was getting more information regarding warehousing trends and innovations. Consequently, the following problem has been selected as the core problem of this thesis:

"Heineken misses insight into warehousing trends and innovations"

Figure 1 illustrates an overview of the problem cluster of this thesis. The core and action problems are colored green and red, respectively.

1.2.4 Research motivation

In the scope of this assignment, warehousing trends and innovations refer to high-level changes happening in the warehousing industry. Trends are dominating patterns or shifts in various areas of society, culture, or fashion that reflect changing behaviors, preferences, and interests over time [8]. Moreover, innovation is about the introduction of new ideas, methods, products, or services that bring about significant improvements or changes in a specific field or industry [9]. The development considered here is related to new technologies in the domain of warehousing essentially. Thus, "trends" refer to what behavior can be observed in warehousing, and "innovations" to new technologies.

This thesis will aim to search for trends in warehouse processes in Europe focusing on warehouse equipment. Warehouse equipment relates to elements, systems, or machines utilized to execute essential tasks, including receiving goods, storing merchandise, managing inventory, transporting items, processing orders, and dispatching goods [10]. Elements regarding the warehouse layout such as sizing, overall structure, or department layout of the warehouses are fixed and thus are out of the scope of this thesis. Having insight into that will allow the company to see the potential development and growth options for their warehouses. Therefore, this will be an opportunity for Heineken to take a step further in warehouse development while improving their performance. The warehouses that will be investigated in this project are the ones situated in Western Europe countries with high wages. This choice was made since human labor represents important expenses for warehouses, and improving the performance of the processes that necessitate a lot of manpower would be a big advantage and could represent a lot of savings.

As explained previously, Heineken is one of the world leaders. The competition pushes companies such as Heineken to constantly reinvent themselves to always perform better, find new solutions to increase their benefits and keep their leading position in the industry. This research is meaningful for the company since the outcome will allow it to reassess its performance indicators by confronting its decision to the standards and choices of other companies, but also to gain insight into new technologies or methods to improve its warehouse processes.

1.3 Research Design

In this section, four sub-questions and the related knowledge questions are listed. This will give an insight into the different steps that will be taken during this project.

1.3.1 Sub-questions

1. How does Heineken measure its warehouse performance?

- *a) What KPIs does Heineken use to measure the warehouse performance?*
- *b) Which KPIs are in the literature relevant to measure warehouse performance?*
- *c) How can Heineken's KPIs be evaluated?*

The first part of this project aims to evaluate Heineken's Key Performance Indicators (KPIs) choices. KPIs are first investigated since they are the base of performance. Indeed, it is very important for companies to use reliable KPIs to measure their performance. To start, the KPIs that the company uses to measure the different warehousing processes' performance will be listed and explained. In line with that, a literature search investigating relevant KPIs for warehouse performance will be made. This will be used as a theoretical base for the benchmark coming up next. The benchmark is a manner to compare and evaluate Heineken's choice about their KPIs, but also to have an insight on the strategy of other companies. The outcome of the benchmark will show similarities and differences between Heineken's KPIs and the standards. From this comparison, it will be possible to give some advice to Heineken about their KPIs choice.

2. What trends and innovations improve the performance of warehouse processes?

a) *Which processes use the most labor in the internal warehouses of Heineken?*
b) *What are the new technologies improving the performance of these warehouse processes?*

The second part of the research is focusing on the performance of the processes, and on finding methods to improve them. For each of the following points, the data necessary will be retrieved from the literature and from the database of Heineken. First, the processes using the most labor in Heineken's internal warehouse will be researched. This will give an indication of which processes should the methods be covering. Then, the trends and innovations for the processes using the most labor will be reported and explained which will give a first indication of what could be the next potential steps for Heineken's warehouses.

3. What innovations are fitting Heineken's processes?

a) How to measure the applicability of the different options to Heineken's processes?
b) What are the most attractive options to implement?

The third and last section of this project has for objective to evaluate the fit of the different options for the company's processes. To do so, a research about their applicability to the company's processes will be done. For that, a literature search will be made to have insight into what is the set of criteria used to evaluate technologies. The trends found in the second section of the project will then be evaluated with the criteria previously found. The outcome of this assessment will result in the choice of one or multiple method(s) that will improve the performance of the selected company's warehouse processes.

1.3.2 Limitations

In this section, the different limitations of this project are listed.

- The research will exclude low-level warehousing innovations since they are too specific and do not fit in the scope of this project. Low-level warehousing innovations can be thought of as an improvement of technologies already applied in the warehouses such as the replacement of a battery with a more powerful one for example.
- A maximum of three innovations for each process will be selected. This will allow the research to be of greater relevance and ensure its applicability to real-world problems, increasing the chance of making a significant impact.

1.3.3 Deliverables

The final steps of this research will be to advise the company regarding the implementation plan of warehousing trends that will improve the performance in Heineken warehouses. To achieve this, various deliverables will be required. The final assignment will comprise the following outputs:

- A benchmark of Heineken's performance KPIs
- An overview of warehousing trends for the warehouse processes in the scope of this research
- A piece of advice on the innovations to further research

2 Performance measurement

In this section, the question researched is *"How does Heineken measure its warehouse performance?"*. To answer this, the mandatory and non-mandatory KPIs of Heineken are listed and explained. Along with that, a literature search looking into theory and case studies is made. Finally, the KPIs of Heineken are evaluated in terms of fit with the observations made in the literature, and a piece of advice for potential modifications is given.

2.1 Heineken's performance indicators

In this section, the KPIs described in the Logistics KPIs Manual [11] and used by Heineken to measure the performance of their warehouses are explained. The Logistics KPIs Manual is composed of a set of KPIs (mandatory), and Process Performance Indicators (PPIs) & Alerts (optional) which are all connected to the Green Diamond (Section 1.2.1). It represents the company's ambition by gathering its four essential drivers: Growth, Profitability, Capital Efficiency, and Sustainability & Responsibility. Logistics KPIs measure the performance of the warehouse processes, the transportation, or the total performance of both. Here, the focus is put on the measurement of warehouse processes, consequently, only the KPIs relating to warehouse performance (or the ones relating to the total performance of warehouse and transport) have been looked into. All indicators listed in this section are extracted from the Logistics KPIs Manual [11].

2.1.1 Mandatory Key Performance Indicators

KPIs are used by companies to be able to measure their progress toward an intended goal. They are a base for decision-making regarding strategic and operational improvement. Mandatory KPIs are the basic metrics that demonstrate a site's performance in an Operating Company (OpCo). Each country in which Heineken has a warehouse is referred to as an OpCo, and each warehouse in this OpCo is referred to as a site. They are compulsory since they facilitate global deployment and ensure compliance with internal and external reporting obligations.
Ten of the forty-nine listed KPIs are mandatory, from which seven are measuring warehouse performance or the total performance of warehouse and transport together. Each KPI belongs to the category of one of the drivers of the Green Diamond.

The specific information in this section was deliberately kept private and not disclosed.

2.1.2 Process Performance Indicators and Alerts

PPIs and Alerts are optional, which means that reporting their data is not mandatory, unlike KPIs. PPIs are achievement goals at the operational level and give insight into more specific data focused on individual processes. Alerts are used to bring up any deviation from the targeted improvement goals. They are both based on business priorities and used when working on improvement in specific areas of the business. PPIs and Alerts are split between the four areas of the Green Diamond in the same way as KPIs.

The specific information in this section was deliberately kept private and not disclosed.

Overview
This subsection has shown different KPIs, PPIs, and Alerts that Heineken uses to measure its logistics processes. The twenty-nine indicators that were previously explained relate to warehouse processes or the total performance of warehousing and transport together. Together they represent business priorities and reveal the improvements toward which the company is working. Growth, profitability, capital efficiency, and sustainability & responsibility are all performance objectives of the company. An ambition is to drive superior growth which means achieving "above-average growth" by focusing on operations efficiency and customer experience. The profitability objectives are including various areas of the company such as productivity, stock management, and cost of the operations but also their complexity and reliability. Furthermore, capital efficiency refers to warehouse utilization and storage. And finally, sustainability & responsibility are related to safety for employees and highlight the environmental consciousness of Heineken and its responsibility regarding this.

Before being able to look for innovations to improve the performance of the company, a check of the KPIs is necessary to understand how will Heineken measure the impact of the innovations that will be advised later in this thesis. This KPIs research will allow in the end, to be able to be more precise with the impact of the innovations on the performance of Heineken, and explain which domain of the green diamond will mostly be impacted by innovations. Doing this overview enables a comparison of Heineken's KPIs with literature and case studies (Section 2.2) in order to investigate which KPIs should theoretically be used by companies and which ones are being mostly used in practice.

2.2 Literature research

In this section, theoretical literature as well as study cases are researched. This is done to give insight into what KPIs should be theoretically used by companies, and which ones are used in practice. The content in this section is used as a base for the review of Heineken's KPIs.

2.2.1 Theory of warehouse performance indicators

The five texts used in this section have been selected taking into account the following criteria. First, the timeliness of the text is important. Indeed, relatively new texts have been investigated which means that this overview includes more up-to-date information. Only Frazelle [12], is an older publication that allows a better insight. Moreover, five different authors have been chosen which offers a more diverse viewpoint and understanding of the topic. Frazelle is chosen since it is widely recognized as a valuable resource in the field of supply chain management and logistics optimization. Naturally, the five texts chosen all align with the same topics of warehouse management, performance indicators, and productivity measurement. Finally, all of them drew a list of KPIs used for warehouse management, which was the aim of the research.

KPIs are indicators used by companies to measure their long-term performance. KPIs are determined according to the company's strategy and reflect their financial, and operational ambitions [13]. KPIs can be classified into multiple different categories depending on the company's preferences. As to be seen in the previous section, at Heineken the KPIs are classified according to the four areas of the Green Diamond. In the following theory research, the three first papers chose to classify their indicators into the following categories: cost, productivity/utilization, quality, and time. Then, the two last pieces of research are categorizing their KPIs in the labor, equipment, and space groups.

Table 1 is a representation of the twenty-five KPIs depicted by Frazelle [12] to measure each warehouse's activities by aligning with the previously stated criteria. Frazelle distinguished productivity and utilization of each other and consequently, uses five criteria for each of the warehouse's activities.

Various theories drew up lists of KPIs for warehouse management, which give insight to companies on the direction that should be taken while (re)constituting their KPIs list. KPIs in various literature for warehouse activities such as receiving, put-away, storage, order-picking, and shipping were also researched [14]. This research brought up a list of seventeen validated indicators that are usable as a benchmark basis for measuring warehouse performance. The indicators that have been selected are filed in the following categories: cost, productivity, quality, time, and utilization. Measuring costs is essential for companies since it allows them to have an overview of their expenses at different levels, and consequently be able to manage them in a better way. Here, the cost category is made up of four KPIs that are: *Labor cost*, *Inventory cost*, *Transportation cost*, and *Insurance cost*. The next category, productivity, also contains four indicators: *Lateness*, *Response to urgent delivery*, *Layout configuration*, and *Implementation of 5S activities*. Furthermore, to measure the quality of the warehouse activities the following indicators are listed: *Product damage rate*, *On time delivery*, and *Accuracy in order delivery*. The two last categories, time and utilization, share six KPIs. For the first category, *Working hours*, *Order lead time*, *Reception time*, and *Average warehouse order cycle time* are the KPIs that are taken on. Finally, the *% Space utilization* and the *Transportation utilization* KPIs are the ones selected to measure the utilization.

Also, KPIs were classified and categorized in similar categories (cost, productivity, quality, and time) [15]. However, the utilization category has been merged with the productivity one here. For each of these categories, this research [15] classified several KPIs by counting the number of times that they were found in

Table 1: Warehouse Key Performance Indicators [12]

	Financial	**Productivity**	**Utilization**	**Quality**	**Cycle time**
Receiving	Receiving cost	Receipts per man-hour	%Dock door utilization	%Receipts processed accurately	Receipt processing time per receipts
Putaway	Putaway cost per line	Putaway per man-hour	%Utilization of putaway labor and equipment	%Perfect putaways	Putaways cycle time (per putaway)
Storage	Storage space cost per item	Inventory per square foot	%Locations and cube occupied	%Locations without inventory discrepancies	%Inventory days on hand
Order picking	Picking cost per order line	Order lines picked per man-hour	%Utilization of picking labor and equipment	%Perfect picking lines	Order picking cycle time (per order)
Shipping	Shipping cost per customer order	Orders prepared for shipment per man-hour	%Utilization of shipping docks	%Prefect shipments	Warehouse order cycle time

specific studies. The investigation in the cost category brought up that *Inventory cost* is by far the most used KPI. Other cost KPIs such as *Order procession cost*, *Labor cost*, or *Maintenance cost* are also listed but are less used in theory. Regarding the productivity category, a total of ten KPIs were researched from which three stand out. Indeed, *Labor productivity*, *Throughput*, and *Shipping productivity* are being found more often in theory than the *Transport* or *Warehouse utilization* KPIs. Warehouse quality indicators found in the literature show that the interest goes more often for KPIs such as *On-time delivery*, *Customer satisfaction*, and *Order fill rate*. These three KPIs are generally more state in theory than one regarding *Shipping*, *Delivery*, or *Picking accuracy* for example. Finally, *Order lead time* comes out as being the most found KPI in the time category. Other KPIs such as *Receiving time*, *Order picking time* are also to be found but more rarely.

Other literature showed another type of classification by choosing different categories: Labour, Equipment, and Space. These three categories were by allocating KPIs and submitting them to expert judgments [16]. For the labor category, the four suggested KPIs (*Labour productivity, Receiving productivity, Put-away productivity*, and *Picking productivity*) were agreed upon by most experts. Differently, in the equipment category where for each of both KPIs (*Equipment utilization* and *Shipping productivity*), one of the experts disagreed and did not have an opinion about it. Finally, the space category was filled up with six KPIs: *Warehouse utilization, Inventory space utilization, Outbound space utilization, Throughput, Turnover*, and *Transport productivity.*

In contrast, [17] classifies warehouse performance KPIs into four categories. The three same categories as [16] are used, to which the Information system category is added. Eleven KPIs were researched and evaluated with the Fuzzy Analytical Hierarchy Process method. The *Space category* came out as getting the highest ranking and is consequently the most valued by the experts that participated in the research. Moreover, the investigation reported that the principal indicators for warehouse productivity performance improvement are *Warehouse management system, Storage space utilization*, and *Throughput.*

Overview

These papers on the theory of warehouse performance indicators give insight into the most important KPIs for each category listed. To start with the financial category; the *Labor cost, Inventory cost*, and *Shipping costs* are the three principal KPIs to consider. Furthermore, regarding productivity and utilization, the three KPIs standing out are *Receiving productivity, Inventory space utilization*, and *Picking productivity.*

Table 2: Cost KPIs

KPIs	[14]	[12]	[15]	[16]	[17]	Total
Labor	✓		✓			2
Inventory	✓	✓				2
Transport	✓					1
Insurance	✓					1
Receiving		✓				1
Put-away		✓				1
Storage		✓				1
Picking		✓				1
Shipping		✓	✓			2
Order processing			✓			1
Cost as % of sales			✓			1
Maintenance			✓			1

Table 3: Productivity and utilization KPIs

KPIs	[14]	[12]	[15]	[16]	[17]	Total
Lateness	✓					1
Response to urgent delivery	✓					1
Layout configuration	✓					1
Implementation of 5S activities	✓					1
Receiving productivity		✓	✓	✓	✓	4
Put-away productivity		✓		✓	✓	3
Inventory space utilization		✓	✓	✓	✓	4
Picking productivity		✓	✓	✓	✓	4
Order prepared for shipment		✓				1
Labor productivity			✓	✓	✓	3
Throughput			✓	✓	✓	3
Shipping productivity			✓	✓	✓	3
Transportation utilization			✓	✓		2
Warehouse utilization			✓	✓	✓	3
Turnover			✓	✓	✓	3
Outbound/staging area utilization				✓	✓	2
Equipment utilization					✓	1
Transport productivity					✓	1

Next, for the quality category five KPIs are slightly standing out: *Product damage rate, On-time delivery, Accuracy order delivery, Perfect order*, and *Storage accuracy.* Finally, about the time category, five KPIs are hardly distinguishable from the others; namely: *Order lead time, Reception processing time, Warehouse order cycle time, Put-away time*, and *Order picking time.* Overall, it can be deduced that the cost, productivity, and utilization of warehouses are central to being able to improve performance. These three domains refer to the profitability area of the Green Diamond of Heineken, where multiple metrics are already defined.

Tables 2, 3, 4, and 5 are a visual representation of each KPI category that has been discussed. Each table reports the number of times that each KPI (rows) was considered in different literature (columns).

2.2.2 Case studies

WERC

To balance with theoretical research, a yearly report on real industry metrics [18] is investigated. This report informs trends and challenges met by companies situated mainly in North America, but also in South America or Europe for example. Their data is based on a survey that managers, directors, or other leading figures of companies answered. For the 2022 report, 240 companies took part in the investigation, with the majority of

Table 4: Quality KPIs

KPIs	[14]	[12]	[15]	[16]	[17]	Total
Product damage rate	✓		✓			2
On time delivery	✓		✓			2
Accuracy in order delivery	✓		✓			2
% Receipts processed accurately		✓				1
Perfect orders		✓	✓			2
Storage accuracy		✓	✓			2
Customer satisfaction			✓			1
Order fill rate			✓			1
Shipping accuracy			✓			1
Picking accuracy			✓			1
Order shipped on time			✓			1
Scrap rate			✓			1
Stock out rate			✓			1

Table 5: Time KPIs

KPIs	[14]	[12]	[15]	[16]	[17]	Total
Working hour	✓					1
Order lead time	✓		✓			2
Reception processing time	✓	✓				2
Warehouse order cycle time	✓	✓				2
Put-away time		✓	✓			2
Inventory days on hand		✓				1
Order picking time		✓	✓			2
Receiving lead time			✓			1
Delivery lead time			✓			1
Queuing time			✓			1
Loading time			✓			1
Dock to stock time			✓			1
Equipment down time			✓			1

them being in the wholesale/distribution and manufacturing industries. Moreover, companies participating in this research are of different sizes and have different strategies and goals. Forty percent of them have the main objective to increase customer satisfaction, whereas another twenty-six percent aim to reduce costs. Furthermore, maximizing profitability is the objective of twenty-three percent of the participating companies, and the maximization of asset utilization is set as the primary goal of the last eleven percent. Regarding the company size, slightly less than twenty percent of the participants have annual sales of less than $100 Million, whereas more than fifty percent of the participating companies report annual sales between $100 Million - $1 Billion. Finally, the last third of participating companies report annual sales of more than $1 Billion.

The WERC report of 2022 [18] announces that the metrics used this year reflect a more balanced approach of the management team of warehouses than the last years. Indeed, an overview of the twelve more used metrics in 2022 revealed the following classification. Table 6 provides definitions of the key operational metrics selected as well as their affiliated metrics category to facilitate the interpretation. The number given to the KPIs in the table refers to their ranking.

Table 6: WERC's KPIs definitions [18]

Category	KPI	Definition
Customer Metrics	3. On-time Shipments	"The percentage of orders shipped at the planned time (shipped means off the dock and in transit to its final destination)."
Operations Metrics	6. Dock-to-Stock Cycle Time, in Hours	"The dock-to-stock cycle time equals the time (typically measured in hours) required to put away goods. The cycle time begins when goods arrive at the receiving dock from the supplier and ends when those goods are put away in the warehouse and recorded into the inventory management system."
	7. Percent of Supplier Orders Received Damage Free	"The number of orders that are processed damage free as a percentage of total orders."
	11. Fill Rate - Line	"Measures percent of orders lines filled according to customer request."
	9. Order Fill Rate	"Measures percent of orders filled according to customer request."
	4. On-time Ready to Ship	"The percentage of orders ready for shipment at the planned time."
Capacity & Quality Metrics	1. Average Warehouse Capacity Used	"The average amount of warehouse capacity used over a specific amount of time (month to month or yearly)."
	5. Peak Warehouse Capacity Used	"The amount of warehouse capacity used during designated peak seasons."
	2. Order-picking Accuracy (Percent by Order)	"This measures the accuracy of the orders picking process where errors may be caught prior to shipment such as during packaging."
Perfect Order Metrics	8. Percent of Orders with On-time Delivery	"The percentage of orders that arrive at their final destination at the agreed upon time."
	12. Shipped Complete per Customer Order	"Measures the percentage of orders which shipped completely, meaning that all line/units ship with the order per agreement between the customer and shipper."
	10. Shipped Damage Free (Outbound)	" This measures the percentage of customer orders shipped in good and usable condition."

Danone

Another study case that is exploited in this thesis is the KPIs of Danone Netherlands. Danone, which takes the twelfth position in the ranking of the biggest FMCG in the world, is similar to Heineken which takes the thirteenth position [19]. An exchange of data between Heineken and the company allowed to access this valuable source [20].

The specific information in this section was deliberately kept private and not disclosed.

2.3 Assessment of Heineken's KPIs

The aim of this thesis is to improve the efficiency of Heineken's warehouse by using trends and market innovations. The goal of the assessment of Heineken's mandatory KPIs is to have an indicator of how is the company measuring its efficiency and performance, and what are their main focus in comparison to what can be found in the literature and other case studies. The focus is on mandatory KPIs since they are the one that needs to be reported, whereas PPIs are optional.

To begin, the description of Heineken's KPIs reveals seven mandatory KPIs focused on warehousing. This number seems low, but when compared to the data received from Danone, there also seven warehousing KPIs are observed. The number of KPIs might be concentrated in order to stay doable and relevant. This is because if the number of mandatory KPIs to be filled in each month (or at the frequency reported) is too large, it could be a factor of discouragement. This could result in harming the good reporting of performance and consequently, reduce their reliability. Thus, regarding the number of KPIs, Heineken uses the right technique and indirectly facilitates the fill-in of KPIs.

Furthermore, the seven reported Heineken mandatory KPIs can be distributed over the different categories (cost, productivity & utilization, quality, and time). This means that the company takes all aspects into consideration. This is an advantage that the KPIs list that was received from Danone did not present since there were no cost and neither time KPIs. However, at Heineken a clear focus of Heineken can be seen since three of the seven KPIs are measuring productivity & utilization. This interest differs from the one found in the case studies since there is a more important concentration of KPIs focusing on measuring the quality of the operations. Indeed, looking at the KPIs of the WERC report in Table 6, nine of the twelve KPIs namely *Order-picking accuracy (percent by order), On-time shipments, On-time ready to ship, Percent of supplier orders received damage free, Percent of orders with on-time delivery, Order fill rate, Shipped damage free (outbound), Fill rate - line* and *Shipped complete per customer order* in the list are related to quality. Moreover, regarding the data of Danone, there also five of the seven KPIs can be classified as quality related. This support the saying of the WERC report [18] that supports that the primary objective of companies switched from reducing costs to increasing customer satisfaction.

Then, in the KPIs of Heineken but also the ones of Danone, one related to safety is listed. This is an element that was not found in the literature. Indeed, the five articles that were used to research the different types of KPIs did not contain any safety indicators. Therefore, the safety indication does not seem a common KPIs choice, however, both companies (Heineken and Danone) do use it. This could be an indicator of the dedication of the companies to diminishing accidents and improving safety in warehouses.

Regarding the choice of the KPIs themselves, it seems to be very personal to each company and each industry. Even if the category of KPIs used in the literature, in the case studies, and by Heineken are approximately the same, the name given to the KPIs themselves are always slightly different, since they are axed in a specific direction which gives to the company in question the possibility to have the overview of interest.

Overview

The KPIs used by Heineken to measure the performance of their warehouse seem to be in concordance with the literature and case studies that were used in this thesis. Indeed, as seen in Table 7 the company deployed its KPIs over the four categories found in the literature. Moreover, the number of KPIs in the mandatory list can be considered average when compared to Danone. In addition, both companies observed showed a tendency of interest regarding safety in the working environment. However, it can be seen in Table 7 that Heineken shows a flaw when the company dedicates only one of its mandatory KPIs in logistics to quality whereas, for both other case studies, quality was a central element. In this KPI category, *Product shipped damage free, On-time shipment* and *Accuracy order delivery* are found a larger number of times than other KPIs in literature and case studies. The three of them are relevant KPIs to measure the quality of the operations at different levels. *Product shipped damage free* indicates the quality of the operation at this level, and alert in case too many products are being damaged. *On-time shipment* measures the quality and performance of the supply chain and gives an indication of the punctuality of Heineken regarding order shipping. Then, *Accuracy order delivery* is about the number of error-free orders.

The aim of this thesis is to improve the performance of Heineken processes with warehousing trends and innovations. Researching KPIs' trends to improve the KPIs' choice of Heineken is done to put light on the performance of certain parts of the process that are not especially looked at now. This would be an opportunity to spot weak points in the process, which would allow to improve the performance of this aspect of the process. Here, the findings showed that other companies measure quality from multiple different angles and that the literature also supports the multiplicity of KPIs in this category, whereas Heineken only uses one quality KPI. The advice of potentially including more quality KPIs could allow them to measure the

Table 7: KPIs per category

	Cost	Productivity & Utilization	Quality	Time
Heineken *				
Literature				
Labor cost	✓			
Inventory cost	✓			
Shipping cost	✓			
Receiving productivity		✓		
Inventory space utilization		✓		
Picking productivity		✓		
Product damage rate			✓	
On-time delivery			✓	
Accuracy in order delivery			✓	
Perfect orders			✓	
Storage accuracy			✓	
Order leadtime				✓
Reception processing time				✓
WH order cycle time				✓
Put-away time				✓
Order picking time				✓
WERC				
Average Warehouse Capacity Used		✓		
Order-picking accuracy (Percent by Order)			✓	
On-time Shipments			✓	
On-time Ready to Ship			✓	
Peak Warehouse Capacity Used		✓		
Dock-to-Stock Cycle Time, in Hours				✓
Percent of Supplier Orders Received Damage Free			✓	
Percent of Orders with On-time Delivery			✓	
Order Fill Rate			✓	
Shipped Damaged Free (Outbound)			✓	
Fill Rate—Line			✓	
Shipped Complete per Customer Order			✓	
DANONE *				

* These KPIs were deliberately kept private and not disclosed.

performance of the processes from a different angle, potentially spot weaknesses, and consequently improve the performance.

3 Trends and innovations

To answer the question *"What trends and innovations improve the performance of warehouse processes?"*, the dispatch of the manpower in processes of internal warehouses with high wages of Heineken will be analyzed. This is researched because labor represents a lot of expense in warehousing. So, improving the performance of processes employing a lot of manpower would lead to a lot of savings. For that, first, a research to find which processes are using the most manpower is done. Then, the methods used for the execution of these processes are researched. Finally, a literature search is made to investigate the trends that would improve the performance of the warehouse processes necessitating the most manpower at Heineken.

3.1 Labor allocation

In this part, the dispatch of the manpower in the processes of Heineken's warehouses is researched. Firstly, it is interesting to understand which Heineken's warehouses are in the scope of this research. At Heineken, warehouses are either 3PL managed or by Heineken directly. The choice of methods and strategies in internally managed warehouses remains within Heineken, differently than in 3PL-managed warehouses where Heineken can influence the decision, but where the final choice is outsourced. In both situations, Heineken plays a role in management choices; consequently, internally and externally managed warehouses are in the scope of this research. Here, the aim is to study warehouses in European countries with high wages. The European countries considered are Switzerland, the United Kingdom, the Netherlands, Belgium, France, Italy, Austria, Germany, Spain, and Portugal. Each of these Opcos has one or multiple sites, all with their own management system.

Researching the most labor-intensive process in Heineken's warehouses is crucial to be able to target the research of innovations around a more specific flow. Data from Heineken's Business Comparison System (BCS) are analyzed to do that. The BCS is used by every site manager to report performance data in different units such as "Production", "Logistics & Distribution", "Quality", "Organization & People Development" as well as "Technical Service & Utilities". It enables the company to keep track of performance in its multiple OpCos. Data representing the allocation of labor is situated in the unit "Organization & People Development". Each site manager registers data about the different FTEs (permanent, fixed-term, and flexible) and the man hours for specific KPIs related to the unit warehousing. For this reason, the precision of these KPIs can vary per OpCos, or per site. For each of the considered OpCos in this project, these data were retrieved from BCS and compared to each other to determine which warehousing process uses the most labor. The precision of the reported KPIs alters the quality of the information since they differ for each site, but also give a very general overview of the logistic flows concerned. Consequently, analyzing BCS's data, revealed that internal transport uses the most labor in the warehousing unit. Yet, the data does not give further specifications about which exact flow. Internal transport refers to the movement of raw materials, products in their manufacturing process, or finished goods on site [21]. So, internal transport can be understood as relating to transport flows of these products from the moment they arrive in the warehouse as empties (unloading docks) until the moment they leave as finished products (loading docks). Empties are related to empty glass bottles that are ready to be filled up in the production lines. Figure 2 represent the internal transport flows to potentially investigate in this assignment. "Unload trucks" is the first step for this process flow, during which trucks coming from external locations and charged with empties are discharged with forklift trucks. After being discharged, the step "store empties" consist of bringing empties to the empty yard where they will be stored. Then, the step "feed the lines" is done by forklift trucks and consists of bringing the empty bottles to the production lines, where they will be filled. The "discharge the lines" step is made of taking Finished Products (FP) and transferring them to their storage locations with the "store FP". The second to last step "pre-stage FP" is about preparing the orders beforehand in order to could charge the trucks efficiently. Finally, the "load trucks" step consists of FP being loaded into trucks for final delivery to clients.

Figure 2: Internal transport flows [22]

Data provided by Heineken are not precise enough to give insight into the internal transport flow that employs the most labor, therefore the flow(s) to investigate are decided depending on their capacity to deal with changes such as innovation or automation for example. At Heineken, a distinction is made between the market side and the production side of these logistics flows. The market side includes unloading trucks and storing empties flows as well as the pre-stage FP and loading trucks. These flows have a high workload fluctuation and are driven by variations in demand and the arrival pattern of trucks. Moreover, these processes have working hours from 16 hours to 24 hours per day, 5 to 7 days per week as well as LSP labor costs being 20 to 30% lower than Heineken labor costs. Feeding the lines, discharging the lines, and storing FP are all three parts of the production side. The production side is a more stable process that encounters less workload fluctuation since it is constrained by the maximum capacity of packaging lines. The production side is active 24 hours per day and has higher labor costs since the labor is employed by Heineken itself [22]. Logistics automation business cases at Heineken generally lean towards more stable flows, consequently the production side flows are more interesting to investigate since applying innovation seems there to be more feasible. This is supported by [23], where it is stated that processes with lower variety will employ process technology with a higher degree of automation.

Figure 3: Internal transport flows in the scope

Figure 3 illustrates the choice of internal transports that are investigated in this project. The production side composed of feeding the lines, discharging the lines, and storing FP was selected due to its stability. Therefore, all processes included in feeding the filling line until storing finished products are included in the scope of this assignment.

Figure 4 describes the production side process flow. Primary and secondary packaging products are both retrieved from their storage location and scanned before being brought to the production lines. Primary packaging refers to empty crates and bottles, and secondary packaging are labels, and other elements necessary for production. After the production process, FP are scanned and brought to storage. A return process also takes place after the production process for damaged or non-compliant products. However, due to the small stature of this process expressed by the company, this process is excluded from the scope of this thesis. ”Production process” and ”Return process” are both colored in gray since they are both excluded from the scope of this thesis. When analyzing the different steps of Figure 4, it shows that researching scanning methods and internal warehouse transport systems are the most relevant in the scope of this thesis.

3.2 Literature search

In this section, the direction of this thesis is determined by the topics found in the literature. Then, for each warehouse process (transport and scanning), three trends or innovations are explained from findings made in the literature.

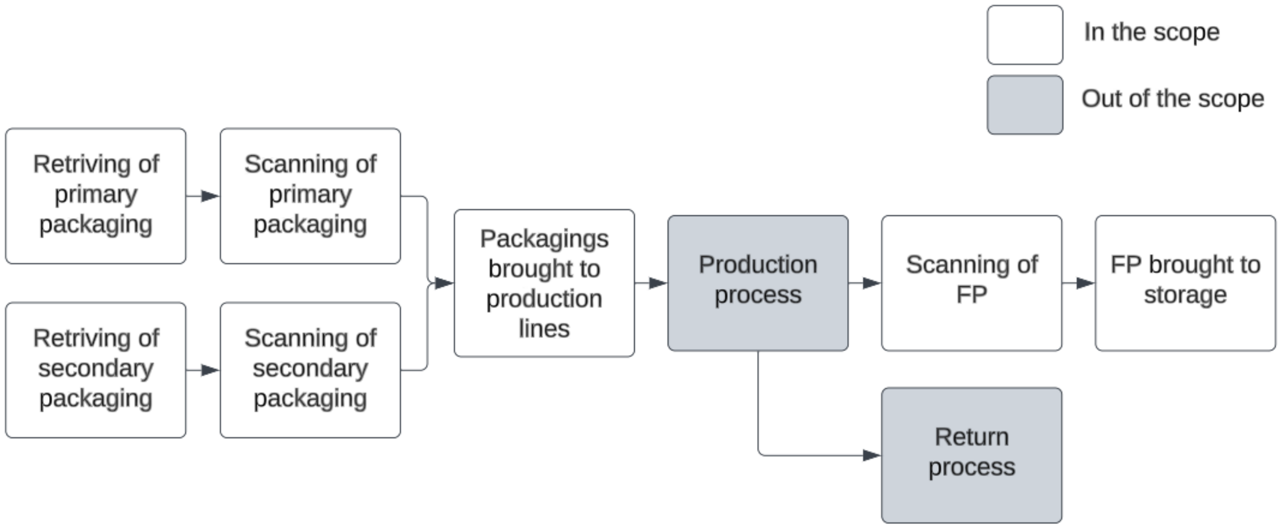

Figure 4: Production side process flow

3.2.1 Context

Recently published literature focus on warehouse technologies such as robotics, automation, autonomous systems, Industry 4.0, Internet of Things (IoT), and smart warehousing. Table 8 summarises them.
With the increasing required labor as well as the enlargement of warehouses' surface, companies need to renew their operations and find new ways to achieve warehousing tasks. Warehouses are getting bigger, and with that, the complexity and variety of operations are developing. The working pace is now more often pushed to the maximum with warehouses operating 24/7. As explained by [24], these elements are encouraging warehousing systems and processes to shift to more automated solutions. [24] researched automation in warehouses while focusing on robotic technologies. The findings flatter the advantages of automation to be savings of space, heating, and lighting but also labor costs, as well as the convenience of its inexhaustible working capacity. Two other papers, [25] and [26], also researched warehouse automation by investigating the topics of automated order picking and flexible automated warehouses respectively. Both studies investigated warehouse solutions and described various automated methods for specific processes. Additionally, [27] provided an overview of operations management within the context of smart warehouses. [27] included a review of equipment automation underlining that warehouses' operation mode will in the future largely be impacted by the implementation of more automated systems, such as warehouse robots for example. The conceptual framework suggested by [28] emphasizes the automated evolution of warehouses. Indeed, this research points out that automated & intelligent warehouses are next and that elements such as integrated Warehouse Management Systems (WMS), the application of Industry 4.0, Artificial Intelligence (AI), etc. are elements of it [28].
Autonomous systems in intralogistics, which are the latest stage of automation, were also researched [29]. This research gives an overview of the different stages of automation of the various warehouse processes (transport, storage, order picking, handling, and packing). This illustrates the direction that trends and innovations took since for each of these processes, automated solutions are to be found. However, as explained by [29], autonomous methods are yet to be further researched. One of them, Autonomous Mobile Robots (AMRs) is already being introduced in various industries. [30] researched AMRs and showed their capacity to help achieve a higher performance of productivity and flexibility.

Other literature researched the impact of Industry 4.0 on warehouses. Industry 4.0 refers to the concept of the Fourth Industrial Revolution and is nowadays a synonym for the digital transformation of the value chain and the smartization of factories [32]. One of the elements of Industry 4.0 is IoT, which was researched by [31] to have more insight into its impact on warehouse management. IoT is a technological solution that connects physical objects in order to facilitate the processing of data. It can also be used to implement detection tools for example, but its aim is to efficiently process administrative necessities such as managing

Table 8: Summary of literature used for the context

Review article	Topic	Concept
Azadeh et al. (2017) [24]	Operation of robotics and automated warehouse systems	Warehouse robotics
Custodio and Machado (2019) [26]	Flexible automated warehouse	Warehouse automation
Jaghbeer et al. (2020) [25]	Automated order picking systems	Warehouse automation
Fottner et al. (2021) [29]	Framework of autonomous intralogistics systems	Autonomous intralogistics systems
Fragapane et al. (2021) [30]	Application, planning, and control of AMR	Autonomous Moving Robots
Kumar et al. (2021) [28]	Warehouse evolution	Industry 4.0, smart warehouse
Zhen and Li (2022) [27]	Smart warehouse operations management	Smart warehouse
Jarašūnienė et al. (2023) [31]	Impact of IoT on warehouse management	Industry 4.0, IoT

inventory for example [31]. IoT will transform the role of human work and understanding this will allow companies to have a strategic advantage [31].

Warehouses' evolution is influenced by digitalization, where connectivity and cyber technologies are massively influencing the economy and society. In the industry, this translated into the development of robotics, and more automated and autonomous systems. The development of smart warehouses is the reflection of this evolution where IoT is employed to digitally perform operations. The concept of Industry 4.0, which is characterized by interconnectivity and automation, encompasses these developments.

3.2.2 Literature search

The technologies found are listed in this section, per category. First, the material handling equipment methods are presented, followed by the scanning methods.

Material handling equipment

Material handling equipment refers to different types of internal warehouse transport systems within the warehouse. These transportation are generally intralogistics, which means that they take place on the warehouse site. The main goal of these internal transports is to move goods from one warehouse process to another in order to relocate goods on schedule with the various warehouse operations. At Heineken, the most used material handling systems are forklifts and conveyor belts. The three technologies that were chosen are AGVs, AMRs, and smart conveyors since they are all innovations related to material handling equipment. Plus, their application is easy to understand since they do not require a huge change in the overall structure of warehouses which could help the company to more seriously consider this proposal and consequently, lead the thesis to have a bigger impact.

AGVs and AMRs

The automation of forklifts brings to the introduction of Autonomous Guided Vehicles (AGVs). AGVs work on the same principle as forklifts, however as their name indicates, AGVs are computer-controlled, wheel-based load carriers designed for horizontal transportation without the need for an onboard operator or driver [30]. AGV navigation predominantly relies on some form of infrastructure, either physical or virtual [33]. Traditionally, AGVs utilize physical infrastructure such as a magnetic stripe or optical stripe as a track to follow. This limitation means that AGVs are restricted to the predetermined path defined by the track. Adjusting the route requires changing the physical track, which is inflexible in the face of rapidly changing transport needs. Although it is still possible to relocate an AGV by moving the physical track, it remains challenging to implement a new path quickly [33]. Alternatively, AGVs can employ a virtual track as a form of infrastructure. Programming the virtual path offers more flexibility compared to a fixed physical path. However, relocating an AGV becomes less flexible with a virtual track as it entails moving the external infrastructure, leading to a time-consuming process to set up again [30] [33]. In summary, AGVs are characterized by their ability to autonomously transport loads, and their navigation can be facilitated by either physical or virtual infrastructure. While both infrastructures provide certain advantages, they also impose limitations that reduce the flexibility of AGVs in general.

The demand for increased flexibility has been a significant driving force behind the advancement of Autonomous Moving Robots (AMRs), encompassing not only improvements in their navigation capabilities but also the range of services they can offer [30]. AMRs are industrial robots that utilize a decentralized decision-making process for collision-free navigation, offering a platform for material handling, collaborative activities, and comprehensive services within a designated area. AMRs' independence from external infrastructure is one defining characteristic, making them highly adaptable in various environments [33]. AMRs utilize a mix of onboard distance sensors and cameras to navigate. The cameras play a dual role by monitoring the path of the vehicle and detecting obstacles. This functionality enables the system to identify both stationary obstacles like boxes and moving obstacles such as people. Through obstacle detection, AMRs can make informed decisions to adjust their route intelligently, aiming to minimize any potential delays in transportation time [30] [33]. However, the absence of a human supervisor who is knowledgeable about the system's limitations poses a significant hurdle, necessitating the robot to self-monitor and respond accordingly [30].

AGVs and AMRs have certain similarities that make them very much alike on some points. Indeed, they are both autonomous robots designed to navigate in a specific environment. They both can be used for material handling and transportation purposes, which result in a certain contribution to increased efficiency and productivity. They could be used to transport primary and secondary packaging to fill the production line, as well as for bringing finished products to storage.

Table 9: Overview of the differences between AGVs and AMRs [33], [34] [35]

Feature	**AGVs**	**AMRs**
Maturity	High	Medium
Payload	High (1500kg)	Low (100-500kg)
On-site installation	Long	Short
Infrastructure modification	Needed	Not needed
Workflow modification	Difficult	Easy
Flexibility	Low	High
Scalability	Low (new infrastructure and tracks must be installed)	High (individual control system)
Maintenance	Easier	More difficult
Speed	3km/h	5-10km/h
Collision avoidance	Path should be free of obstacles	Ability to deviate to avoid obstacles

However, there exists also a number of differences that distinguish both robots. AGVs and AMRs present dissimilarities when looking at their reliance on the infrastructure, flexibility, decision-making as well as control system. The control system between AGVs and AMRs differs largely since the first one is directed by a central control unit (centralized control system) whereas AMRs are provided with a decentralized control system, meaning that they are able to control themselves without receiving commands from a control unit [30]. Table 9 highlights and recapitulate the multiple differences between AGVs and AMRs.

Yet, even if these two technologies are popular, AGVs and AMRs are not new on the market. AGVs have been introduced for the first time in 1955 [30] and AMRs in 1987 [36], and since then their popularity is not fading. As stated by [30] and researched by [37], in 2017 the number of globally installed AGV and AMR systems was estimated at more than 13,000. Furthermore, according to the DHL Logistics Trends Radar 6.0 [38], "AMR sales in the logistics industry are expected to grow by 31% per year between 2020 and 2023". Overall, between 2016 and 2021, the annual installation of industrial robots increased by 11% [39].

Nowadays, AGVs and AMRs are still very well known for industrial purposes. The last edition of LogiMAT [40], exposed a certain number of new driverless transport systems, or solutions to improve the use of the ones already marketed.

Smart conveyors

Another material handling system also commonly used in the industrial sectors is the conveyor belt system that ensures the transportation of material or products from one location to another in different environments. Production processes are usually irregular, making the transport load of belt conveyors non-uniform throughout the day but running at a fixed speed. However, running at a fixed speed regardless of the charge, or necessity results in low power efficiency as well as an important waste of this power [41]. Finding a solution to improve the use of energy for conveyor systems would improve the process efficiency. Speed regulation's effect on the energy consumption of conveyor belts was studied and advised to save energy consumption [42]. Smart conveyor systems have been found as being interesting to improve the efficiency of belt conveyors by being more flexible, and able to transfer products at different speeds [43] by using smart sensors, motion control, and AI [44]. This improved efficiency is translated by energy saving achieved by using a speed control system based on the load [41], powered by AI [44]. AI installed on smart conveyor systems also has the capacity to shut down conveyor operations during off-peak periods, still with the aim of conserving energy [44]. A simulation study [45], proved that an active speed control on a belt conveyor system could lead to more efficient (and sustainable) operation by saving electricity costs and diminishing CO2 emission. Smart conveyors also have more features, such as predictive maintenance which results in less downtime, since the conveyors can monitor themselves and detect when maintenance is necessary [44].

Scanning methods

In the process of interest in this thesis, each pallet needs to be scanned at least twice; before being sent to production, and before being brought to storage. Scanning these pallets manually, the traditional way costs approximately 5 seconds per pallet. Diminishing the duration of this process or eliminating it would result in a gain of time and money for the company, which would consequently improve the process efficiency. Therefore, the following findings are aiming to replace with a more automatized operation, the manual scanning process, principally at Heineken.

Automatic barcodes scanning

Barcodes are used daily to tag and identify items during the production process in the industrial sector. Barcodes provide a simple and cost-effective way of presenting varied commerce data [46]. Increasing the speed of the barcode scanning process could result in improving the efficiency of automatic scanning. Years ago already, barcode scanning methods with this purpose have been looked into, where different challenges were addressed [47]. Nowadays, various companies researched methods to accelerate the scanning process, or even remove it, and some of them came out with the prototype of scanning gate or pall [48], [49], and [50]. VIMAAN [48] and AIT Goehner [49] have commercialized the concept of scanning gates where captors on top and side of the gate can scan multiple barcodes at a time, while a material handling system such as a forklift goes through it. Similarly, Cognex [50] commercialized a pall that does the same job as the gate, however only scanning barcodes from one side of the forklift. These methods have multiple advantages of which the gain of time is one since the scanning step of the process can be skipped and automatically be carried out when products are transported to the filling lines or stocking locations. Moreover, it eliminates the need to carry individual hand gadgets for the workers, or any adaptation of the working environment which is for example necessary when starting to work with Radio Frequency Identification (RFID) for example [51].

Radio Frequency Identification

In recent years, RFID technology has gained significant global attention. RFID transponders can be integrated into pallets, but also in shelves or boxes. They can be used durably and in every environment since their readability is not affected by dirt or scratches for example [52]. The preference for passive RFID tags has emerged due to their cost-effectiveness, minimal electronic components, and independence from a power source. These characteristics make passive RFID tags highly suitable for a wide range of applications, including efficient localization in warehouse logistics [53]. RFID technology is increasingly recognized as a promising successor to traditional barcodes in various applications. In addition to its primary function of providing identification and traceability, RFID offers distinct advantages over barcodes. They have the capability to read many tags at once, regardless of how they are positioned and can work through different packaging materials. This versatility enables efficient monitoring of inventory in warehouses, where RFID readers can be strategically positioned at entrances to facilitate easy and accurate inventory tracking [54] [55]. Comparable to the gate scanning system, these RFID readers are installed as gates under which forklifts or other material handling systems can drive, and get their pallets automatically detected [54]. Another way to scan these RFID tags would be to equip forklifts or other material handling systems with sensors in order for the transported pallets equipped with RFID, to be associated with the position of the forklift at the time of unloading event [56].

Image recognition

Pallet scanning is done for inventory count but also to be able to keep track of pallets through the warehousing process. Technologies using image recognition such as doks.ceiling [57] are able to do both can be very advantageous. The doks.ceiling is a system that deploys cameras in warehouses that are equipped with image recognition and that are able to track pallets when they are being transferred in the different areas of the warehouse. These camera modules are installed to the ceiling of the warehouses, software, and algorithms. The cameras are positioned so that the warehouse's complete surface area is covered [57].

More widely, the utilization of automatic identification technology has become a highly effective method for swiftly and accurately acquiring and inputting data, resolving the challenges associated with slow data input speed and a high error rate [58]. Image recognition can be used to identify and track the movement trajectory of warehouse personnel, work clothes, and safety helmets. It is able to distinguish the object of interest from the background and determines its categorical classification and spatial coordinates [59]. This allows for a comprehensive understanding of the foreground and background elements within the captured images. Moreover, image recognition has also shown advantages when used in warehouse management. The system has powerful capabilities to perceive information from the environment where it performs, and can provide robust levels of recognition for object classification [60].

Innovations as doks.ceiling encourages the automation journey, during which it helps reduce the number of operators, and offers up-to-date data as well as time savings. It also seems to eliminate the step of scanning in warehousing which could be very advantageous. Moreover, this innovation can easily be integrated into warehouses' ceilings since no additional infrastructure is necessary. The limitation of the doks.ceiling is that is made for indoor use, however, this is not a problem for the processes that are being investigated since feeding the production lines and stocking finished products are indoor activities.

4 Measuring innovations' applicability

This section explores the process of technology evaluation and answers the question *"What innovations are fitting Heineken's processes?"*. First, selection criteria related to the fit, impact, and financial value of the innovation are highlighted. Then, according to these criteria, the previously found technologies are evaluated in terms of applicability.

4.1 Innovations' evaluation: literature research

After finding multiple innovations and trends related to material handling and scanning methods, the process of evaluating them is primordial. Evaluating innovation properly is crucial in order to improve the efficiency and productivity of the processes in question. The choice of an innovation over another one is made in accordance with assessment criteria that help highlight the advantages and disadvantages of each innovation. The following section will discuss the three sets of criteria to use to evaluate technologies.

4.1.1 Innovations' fit

Firstly, it is important to have an overview of the fit of the technology with the process that it has been chosen for. This reflection is articulated around three dimensions that vary according to the variety and volume of the processes. The degree of automation, the capacity of the innovation to do the work for which it is intended, and its connectivity to other technologies [23] are considered. According to Slack et al., [23], high-volume-low-variety processes can use technologies with more dedicated purposes, larger scale, and that are relatively inflexible compared to low-volume-high-variety processes. Scalability, which is defined as the capacity of a system to adjust its performance and cost according to the fluctuations in application and system processing demands [61], also adjusts according to variety and volume. Indeed, if the variety of the process is low and the volume is high, the scalability of the technology should be higher than the one of a process with high variety and low volume [23]. Finally, coupling involves connecting separate activities within a process technology to create an interconnected system. Tight coupling leads to faster throughput but can be expensive and susceptible to failures. It is more suitable for operations with high volume and low variety. On the other hand, processes with higher variety require a broader level of coupling [23].

Table 10: Overview of the fit criteria for innovations

Criteria	High-variety low-volume process	Low-variety high volume process
Degree of automation	Low	High
Scalability	Low	High
Coupling	Broad	Tight

4.1.2 Innovations' impact

Furthermore, the impact of the innovation on the process should also be taken into account. To measure this, five operation performance objectives are identified in the following points [23], [62], [63]. The aim is to be able to evaluate the impact of innovation on each of these targets.

- *Quality* - A positive impact on the quality of the process can be expected, such as the reduction of human error.
- *Speed* - The speed of the process may be improved. For example, the scanning time with the innovation could be decreased compared to when it is done manually.
- *Dependability* - If the expected breakdown time of the innovation is smaller than the one of the operators (if applicable), then the innovation will be improving the dependability of the operation.
- *Flexibility* - The expectations regarding flexibility are mitigated. Generally, automated innovations are less flexible than manual systems, where humans can easily adapt to change. However, automated innovation can have longer or shorter working days, depending on the demand.
- *Cost* - With automated innovations, the cost factor will on one side increase for engineering services and maintenance, but on the other side labor costs will most probably decrease [23].

4.1.3 Innovations' financial value

Lastly, as seen with the last previous criterion, the financial value of implementing innovation is also a decisive factor. Indeed, the advantages of investing in new technology can be enjoyed over an extended period of time in the future, whereas the costs associated with the investment are typically incurred at the initial stage. For this reason, it is important to consider the time value of money [23]. For that, the payback period which is the duration required to recoup the investment cost is a good indicator. A shorter payback period is generally preferred over extended ones [64]. In most cases, companies accept a payback period of two years, but this number can go up to five years maximum.

4.2 Innovations' evaluation: in practice

The practical evaluation of the innovations aims to evaluate the one fitting the company. For that, material handling equipment, as well as scanning methods, are reviewed according to the criteria found in the literature. The innovations applicable to Heineken are also pointed out.

4.2.1 Material handling equipment

Material handling systems play an important role in warehousing since they are responsible for all movements of goods from the moment a product enters the warehouse until it leaves it. Manual material handling systems work at the speed of the operator that is using them. However, automated material handling systems comply with the way they have been programmed. Internal transportation has a lot of impact on the efficiency of the warehousing process. Therefore, automating or reducing costs is an interesting way to improve warehouse efficiency.

AGVs

For this section, the assumptions found in Table 11 are considered.

Table 11: Assumptions

Topic	Assumption	Source
AGV cost	€ 125,000	Company's indication
Forklift cost	€ 100,000	Company's indication
Maintenance cost	10% of the initial product cost	Indication
Salary maintenance	€ 60	Company's data
Installation cost	30% of the initial product cost	Company's data
Gross personnel cost per employee	€ 39	Company's data
Operator salary	€ 39	Company's data
AGVs per operator	20 for 1	Indication

Another assumption made for these calculations is that the floor of the warehouse in which AGVs will be implemented is in good condition enough in order to allow their smooth motion. In the case that this is not the case, the business case would differ from the upcoming one since the ground should be replaced or renovated according to its state. For a warehouse of 40,000 m^2 as Zoeterwoude, it is estimated that 70% of the warehouse is a storage place, thus 12,000 m^2 are driving paths that would need to be renovated or replaced. Considering that the floor is made of reinforced polished concrete and that the cost per square meter is about €44 [65], the cost of this intervention would raise to more than €500,000. It is consequently an element to consider if the application of AGVs is considered.

The implementation of AGVs is an interesting option that needs to be researched further. To this aim, it is important to understand the benefits of this implementation in comparison to the actual system. At Heineken, the principally used material handling system is the forklift, which is a manual material handling system, driven by humans. AGVs and forklifts are used for the same purpose in a warehouse since they are both meant to transport pallets from one location to another one. Figure 5 illustrates the type of AGVs that is considered in this section, they not following a path but a more flexible, and are able to lift their load three levels high.

Figure 5: Automated Guided Vehicle [66]

Replacing the forklift system of a warehouse with AGVs needs preliminary calculations, in order to have an overview of the financial value of the operation. For the upcoming calculations, the rule of thumb used is that to replace one forklift, three AGVs are required. This is because an AGV can only do a third of the amount of work that one forklift does in one hour, due to the reduced speed that an AGV can achieve (3-4km/h) compared to a forklift system (10-15km/h). The costs are calculated on the basis that the warehouses are running 24h per day, for five, six, or seven days a week.

Starting with the investment cost, it can be seen in Table 12 that implementing three AGVs is approximately seven times more expensive than using a simple forklift for material handling. The calculation of the installation costs is assumed using the assumption that 30% of the product investment cost. This assumption is taken based on a document shared by Heineken about the financial overview related to AGV investment. Indeed, this overview showed that the installation cost of AGVs is approximately equal to 30% of the initial investment cost. This relation for the installation cost is then taken as an assumption for this innovation as well as for all the following ones of this thesis. However, the main drivers of change are not the investment costs but the yearly costs that are cheaper for AGVs compared to forklifts.

The calculation of the yearly costs regarding maintenance and equipment costs can be found in Table 13. There it was assumed that the maintenance cost is equal to 10% of the product investment cost. Moreover, the salary cost for maintenance per unit is of one hour per week, fifty-two weeks per year with a salary of €60/hour for AGVs and forklift maintenance. It was communicated by the company that the gross personnel cost per employee is approximately 70.000 €/year, which would make the cost per hour equal to 39 €/hour if working 1,800 hours per year. The difference observed between five, six, and seven days working in a week is coming from the cost of energy and salaries increasing for AGVs and forklifts as the number of days increases. The bigger difference can be seen in Table 13 where the salary for the forklift driver increases simultaneously with the number of days during which the warehouse runs. For this calculation, it was assumed that the

Table 12: Initial costs for AGVs and forklift

Subject	Description	AGV	Forklift
Investment costs	Product cost (per unit)	€ 125,000	€ 100,000
	# of AGVs/forklifts	3	1
	Total product investment	€ 375,000	€ 100,000
	Installation cost (per unit)	€ 35,000	€ -
	Total installation cost	€ 105,000	€ -
	Total investment cost	€ 480,000	€ 100,000
5 days/week			
Yearly costs	Maintenance costs (equipment etc)	€ 37,500	€ 10,000
	Salary	€ 43,150	€ 245,575
	Energy	€ 3,136	€ 1,608
	Total yearly cost	€ 83,785	€ 257,183
6 days/week			
Yearly costs	Maintenance costs (equipment etc)	€ 37,500	€ 10,000
	Salary	€ 51,854	€ 294,715
	Energy	€ 3,763	€ 1,930
	Total yearly cost	€ 93,117	€ 306,645
7 days/week			
Yearly costs	Maintenance costs (equipment etc)	€ 37,500	€ 10,000
	Salary	€ 60,466	€ 343,824
	Energy	€ 4,390	€ 2,251
	Total yearly cost	€ 102,356	€ 356,075

Table 13: Salary costs for AGVs and forklift

Subject	Description	AGV	Forklift
Control/maintenance	Hours / week (5 days/week)	2.13	0.71
	Hours/week (6 days/week)	2.58	0.86
	Hours/week (7 days/week)	3	1
	Weeks/year	52	52
	Salary/hour	€ 60.00	€ 60.00
	Total/year (5 days/week)	€ 6,645.60	€ 2,215.20
	Total/year (6 days/week)	€ 8,049.60	€ 2,683.20
	Total/year (7 days/week)	€ 9,360	€ 3,120
Forklift driver (3 drivers/forklift/day)	Hours/day		24
	Days/week		5,6 or 7
	Weeks/year		52
	Salary/hour		€ 39
	Total/year (5 days/week)		€ 243,360
	Total/year (6 days/week)		€ 292,032
	Total/year (7 days/week)		€ 340,704
AGV operator (1 operator per 20 AGVs)	Hours / day	24	
	Days/week	5, 6 or 7	
	Weeks/year	52	
	Salary/hour	€ 39	
	Ratio (1 operator for 20 AGVs)	0.15	
	Total/year (5 days/week)	€ 36,504	
	Total/year (6 days/week)	€ 43,804.80	
	Total/year (7 days/week)	€ 51,105.60	
Total	Total salary costs (5 days/week)	€ 43,149.60	€ 245,575.20
	Total salary costs (6 days/week)	€ 51,854.40	€ 294,715.20
	Total salary costs (7 days/week)	€ 60,465.60	€ 343,824

gross personnel cost is the same for all employees. Finally, the yearly energy costs are also calculated considering that an AGV system uses 35% less energy than a forklift system [67], [68]. As to be seen in Table 14, data given by Heineken revealed that a forklift uses an average per year of 10,700kW while working seven days per week. Therefore, three AGV systems also working seven days per week will be using about 6,955kW per year.

The value of the energy use is calculated with an electricity cost of roughly €0.21/kW in Europe [69]. This is a variable value that can bring changes to the calculation if it would come to rise up. Taking into consideration this, it can be seen in Table 12 that three AGVs use around two times more energy than one forklift which could represent a certain cost that could generate a potential perplexity. This could be solved by the implementation and use of sustainable energy such as solar panels for example.

Table 14: Energy use for AGVs and forklift

Subject	Description	AGV	Forklift
kW/year/machine	5 days/week	4968	7643
	6 days/week	5,961	9,171
	7 days/week	6,955	10,700
Costs	1 kWh	€ 0.21	€ 0.21
	Total/year (5 days/week)	€ 3,135.71	€ 1,608.06
	Total/year (6 days/week)	€ 3,762.85	€ 1,929.67
	Total/year (7 days/week)	€ 4,390	€ 2,251.28

When comparing both technologies, it is interesting to have an idea of when the implementation of an AGV system would become less expensive than the use of forklifts. Table 12 shows that the yearly costs caused by the use of forklifts are drastically higher than the ones for the AGVs, especially as the number of days worked in a week increases. Thus, it is known that the more days the warehouse runs, the faster will the AGV system be profitable. Figures 6, 7,and 8 illustrate this idea, where indeed, it can be seen that the profitability of AGVs increases with the number of days during which the warehouse runs.

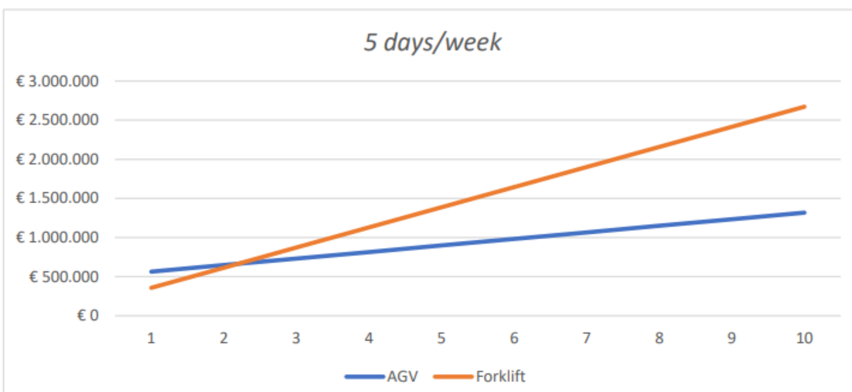

Figure 6: Profitability curve: 5 days running

The number of years necessary for AGVs to become more profitable can be calculated according to Equation 1 with:

InvFL = Total investment cost for forklifts
Cost#DaysFL = Yearly cost per number of days running for forklifts
InvAGV = Total investment cost for AGVs
Cost#DaysAGV = Yearly cost per number of days running for AGVs

$$InvFL + (Cost\#DaysFL)x = InvAGV + (Cost\#DaysAGV)x \rightarrow x = \#Years \tag{1}$$

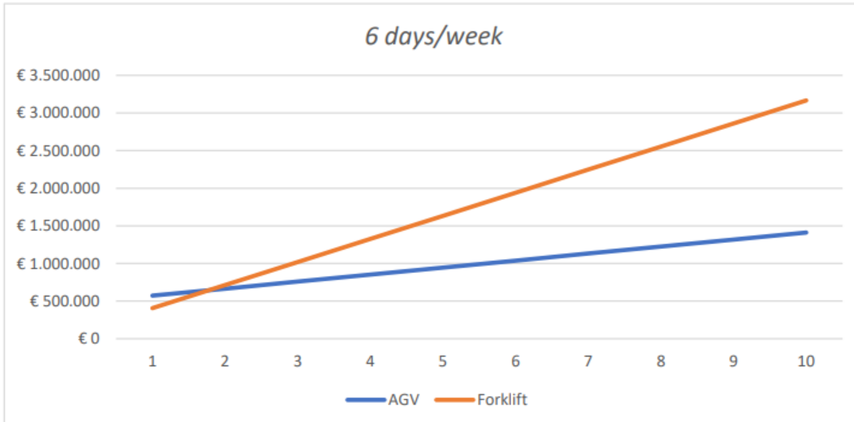

Figure 7: Profitability curve: 6 days running

Table 15 shows the number of years (x) necessary for AGVs to be more profitable than forklifts depending if the warehouse in which they were implemented runs five, six, or seven days.

Table 15: Profitability of AGVs

# of days the warehouse runs	x
5	2.19
6	1.78
7	1.50

These observations allow saying that the highest the number of running days in a warehouse, the fastest will AGVs be beneficial. However, regardless of the number of days during which the warehouse runs, their implementation will always be more profitable to Heineken than using the forklifts for five years and changing them. Moreover, it is known that at Heineken, the forklift systems installed in warehouses are renewed every five years, which means that after five years the benefice of implementing AGVs becomes even bigger, assuming that AGVs have a lifetime longer than five years. If this assumption is overlooked, the AGV system would still be beneficial since the period of time necessary for it to be more profitable than the forklift system is inferior to five years for all three observations. This period of time is also influenced by the assumptions of the maintenance cost per year and installation cost. The decrease or increase of these ones would bring differences as of the period until profitability of the AGVs. This is because installation costs are only necessary for AGVs and then, their increase or decrease could create a new balance for the calculation.

Table 38, used to generate Figures 6, 7, and 8, can be found in Appendix A.2.

The payback period for the implementation of AGVs can be calculated with Equation 2.

$$PaybackPeriod = \frac{Investment}{ExpectedReturnOnInvestment} \tag{2}$$

The expected return on investment, shown in Equation 3 is calculated by subtracting the yearly cost of AGVs from the yearly costs of forklifts.

$$ExpectedReturnOnInvestment = YearlyCostForklift - YearlyCostAGV \tag{3}$$

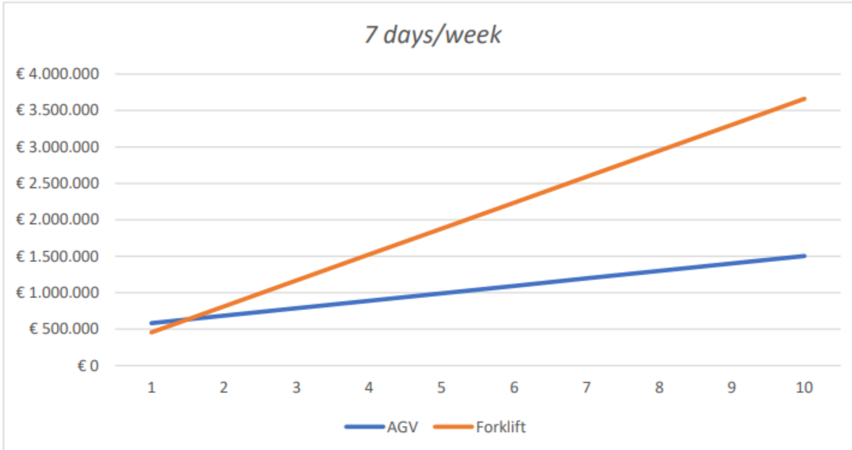

Figure 8: Profitability curve: 7 days running

Table 16 shows the payback period of AGVs if the warehouse in which they are implemented runs five, six, or seven days.

Table 16: Payback period

# days the warehouse runs	Payback period (years)
5	2.77
6	2.25
7	1.89

It can be seen that the payback period is always less than three years regardless of the number of days that the warehouse is active. This leads to the conclusion that AGVs could be an interesting option for Heineken.

AMRs

AMRs are even newer warehouse innovations than AGVs, which could also be used to replace manual forklifts, in order to transport pallets to the filling lines or to transport the finished goods pallets to their storage location. They have also several advantages since they are highly autonomous, very flexible and scalable, their installation is very quick and they participate in improving the safety in the warehouses with their anti-collision system. They also contribute to reducing labor costs [70], [71]. Some disadvantages specific to AMRs are also to be taken into account. AMRs are for now limited to a very restricted payload (max 500kg) and are consequently designed for light tasks. However, a full pallet at Heineken weighs approximately 1000kg which makes its transportation by an AMR not possible. Nevertheless, it was seen in Table 9, AMRs are still at a medium stage of maturity and this issue might be solved in the future. Moreover, they necessitate a lot from the environment in which they perform, since the quality of the ground should not be too uneven, and too much dust is also crippling [70], [71].

Figure 9: Autonomous mobile robot [72]

AMRs offer a lot of advantages, however, they also present some crippling negative points which limit their implementation in various processes. For this reason, at Heineken, AMRs' implementation does not constitute a valid business case. Nevertheless, their qualities are interesting and could play an important role in the improvement of the safety and efficiency of warehousing processes. Therefore, in the future, it will be insightful to keep an eye on this innovation as it matures.

Smart conveyors

At Heineken, conveyors are already used after the filling lines, and before being charged on the forklifts to be brought to storage. Consequently, smart conveyors could also be used at the same stage of the process. Implementing smart conveyors would have the advantage of reducing the power consumption of the regular conveyor belt [73], [45]. Some negative points of smart conveyors are the risk of over-tension of the belt, or of the motor over-heating. However, these details can be solved by optimizing the system [73]. They can also be very bulky in the warehouse. They should be placed strategically in order to diminish the necessity for crossing them. Moreover, maintenance costs as well as their scalability with other new technology can also be challenges.

Figure 10: Conveyor system [74]

Smart conveyors are similar to regular conveyors as to be seen in Figure 10. They differ in the connectivity of smart conveyors compared to regular ones. However, the principle and look stay the same. Smart conveyors with speed control have been recognized as reducing the quantity of power from 3% until 19% when compared to the constant speed belt conveyor systems [75]. This is confirmed by another study [45], that researched the effect of active speed control on conveyor belts and found that the average electrical power consumption went from 95kW with constant speed to 79kW with variable speed, which reduce the consumption of 16.05%. The predicted annual electrical consumption when using variable speed conveyors would decrease from 304.06kW to 254.78kW. With that, the predicted annual electrical cost would also decrease from €24933.25 per year to €20892.29 per year, leading to a total annual savings of €4508.43 per year. This type of savings is interesting for all companies, however, the implementation cost of the technology also needs to be considered, as well as the yearly costs that it incurs. The different assumptions taken in this section are listed in Table 17.

Smart conveyor versus conveyor

Smart conveyors could be used to replace regular conveyors or to replace forklifts. Beginning with regular conveyors, the investment cost calculated in Table 18 are illustrating the initial costs for a conveyor and smart conveyor of 10 meters. The cost of the turning station of a smart conveyor is estimated to be the same price as the one of a normal conveyor since they are effectuating the same tasks. However, the price of a straight conveyor (going in one direction) is estimated to be 25% more expensive than for a basic conveyor due to the smart technology that is integrated with it. Both installation costs have been calculated following

Table 17: Assumptions taken for regular and smart conveyors

Topic	Assumption	Source
Regular conveyor		
Cost turning station	€ 50,000	Company's indication
"Straight" conveyor	**€ 10,000**	Indication
Maintenance cost	10% of the initial product cost	Indication
Installation cost	30% of the initial product cost	Company's data
Salary maintenance	€ 60	Company's indication
Maintenance time	**30min/10 meters/week**	Company's indication
Smart conveyor		
Cost turning station	€ 50,000	Company's indication
"Straight" smart conveyor	**€ 12,500**	Indication
Maintenance cost	10% of the initial product cost	Indication
Installation cost	30% of the initial product cost	Company's data
Salary maintenance	€ 60	Company's indication
Maintenance time	**45min/10 meters/week**	Indication

the same assumption as by the AGVs, where 30% of the cost of the product itself is equal to the installation costs. The total investment costs for a smart conveyor are greater than for a basic one. This is not surprising since the advantage of the smart conveyor is its ability to reduce yearly energy costs. The investigation is interesting in order to find out whether the reduction in energy is great enough, in order for the smart conveyor to become more profitable than a basic conveyor after some years.

Table 18: Initial cost of smart conveyor and conveyor

Subject	Description	Smart conveyor	Conveyor
Investment costs	# of turning station	2	2
	Cost turning station	€ 50,000	€ 50,000
	Total cost turning station	€ 100,000	€ 100,000
	Straight conveyor (meter)	8	8
	Cost/meter conveyor	€ 12,500	€ 10,000
	Total cost straight conveyor	€ 100,000	€ 80,000
	Investment conveyor	€ 200,000	€ 180,000
	Installation costs	€ 60,000	€ 54,000
	Total investment costs	€ 260,000	€ 234,000
5 days/week			
Yearly costs	Maintenance costs (equipment etc)	€ 20,000	€ 18,000
	Salary	€ 1,671	€ 1,114
	Energy	€ 31,794	€ 37,872
Total yearly cost		€ 53,465	€ 56,986
6 days/week			
Yearly costs	Maintenance costs (equipment etc)	€ 20,000	€ 18,000
	Salary	€ 2,006	€ 1,337
	Energy	€ 38,152	€ 45,446
Total yearly cost		€ 60,158	€ 64,784
7 days/week			
Yearly costs	Maintenance costs (equipment etc)	€ 20,000	€ 18,000
	Salary	€ 2,340	€ 1,560
	Energy	€ 44,511	€ 53,021
Total yearly cost		€ 66,851	€ 72,581

As seen in Table 18, the yearly costs are calculated including maintenance costs, salary, and energy costs. The conveyor systems (regular and smart) do not require human intervention to function, so the salary cost reflects the salary for the maintenance. For the cost of maintenance, the same assumption is once again used, which means that 10% of the cost of the product itself is assumed to be equal to the yearly maintenance costs. Moreover, the salary cost of the maintenance differs depending if the warehouse runs for five, six, or seven days and fifty-two weeks per year. A basic conveyor is estimated to require a weekly 30 minutes of maintenance per 10 meters while the warehouse runs seven days a week non-stop. A smart conveyor of also 10 meters is estimated to require 15 minutes longer of maintenance each week. The different salary costs are calculated in Table 19.

Table 19: Salary cost smart conveyor and conveyor

Subject	Description	Smart Conveyor	Conveyor
Control/maintenance (for 10 meters)	Hours / week (5 days/week)	0.54	0.36
	Hours/week (6 days/week)	0.64	0.43
	Hours/week (7 days/week)	0.75	0.50
	Weeks/year	52	52
	Salary/hour	€ 60	€ 60
	Total/year (5 days/week)	€ 1671.43	€ 1114.29
	Total/year (6 days/week)	€ 2005.71	€ 1337.14
	Total/year (7 days/week)	€ 2340	€ 1560

Table 20: Energy use of smart conveyor and conveyor

Subject	Description	Smart conveyor	Conveyor
Consumption	Energy consumption (ratio)	0,84	1
	Consumption per meter [kWh]	2,52	3
	# of meters	10	10
	Consumption per conveyor [kWh]	25,19	30
Costs	Cost per kWh	€ 0,21	€ 0,21
	Total / hour	€ 5,30	€ 6,31
	Total / year (5 days/week)	€ 31.794	€ 37.872
	Total / year (6 days/week)	€ 38.152	€ 45.446
	Total / year (7 days/week)	€ 44.511	€ 53.021

The energy use of smart conveyors is calculated in Table 20. There, the assumption ratio of 0,84 is used since it was found earlier that smart conveyors consume 16,05% energy less than basic conveyors [75], [45]. Table 20 shows that the energy consumption of smart conveyors is always lower than the one of basic conveyors regardless of the number of days that the warehouse runs, which confirms the findings made in the literature. In addition, the assumption regarding the investment cost of the smart conveyor is not much higher than the investment costs of the conveyor. Thus, for the smart conveyor to become beneficial, the yearly costs it incurs should be largely lower than for basic conveyors. It can be seen in Table 18 that this is the case, however, this difference should be big enough in order to constitute a good business case.

Table 21: Profitability of smart conveyor over 10 years

	5 days/week		6 days/week		7 days/week	
year	Smart conveyor	Conveyor	Smart conveyor	Conveyor	Smart conveyor	Conveyor
1	€ 313,465	€ 290,986	€ 320,158	€ 298,784	€ 326,851	€ 306,581
2	€ 366,930	€ 347,973	€ 380,316	€ 363,567	€ 393,702	€ 379,162
3	€ 420,395	€ 404,959	€ 440,474	€ 428,351	€ 460,553	€ 451,742
4	€ 473,860	€ 461,945	€ 500,632	€ 493,134	€ 527,404	€ 524,323
5	€ 527,325	€ 518,931	€ 560,790	€ 557,918	€ 594,255	€ 596,904
6	€ 580,790	€ 575,918	€ 620,948	€ 622,701	€ 661,106	€ 669,485
7	€ 634,255	€ 632,904	€ 681,106	€ 687,485	€ 727,957	€ 742,066
8	€ 687,720	€ 689,890	€ 741,264	€ 752,268	€ 794,808	€ 814,646
9	€ 741,185	€ 746,877	€ 801,422	€ 817,052	€ 861,659	€ 887,227
10	€ 794,650	€ 803,863	€ 861,580	€ 881,835	€ 928,510	€ 959,808

Yet, Table 21 shows the yearly costs over 10 years of investing in a smart conveyor and the one of investing in a normal one. It can be seen that between both technologies, the difference in cost is very small but after a specific number of years using a smart conveyor become cheaper than using a regular one. Indeed, if the warehouse runs five days a week, then using a smart conveyor would become cheaper than using a regular one between 7 and 8 years after implementation. Similarly, if the warehouse runs six and seven days a week, the smart conveyor would become less expensive than the regular one between 5 and 6 years and 4 and 5 years respectively.

To find out the exact number of years (x) until a smart conveyor becomes more profitable than a regular conveyor, Equation 1 is used.

Table 22: Profitability of smart conveyors

# of days the warehouse runs	x
5	7.38
6	5.62
7	4.54

Table 22 shows that the more days the warehouse runs, the faster will the smart conveyor become profitable. If the lifetime of a conveyor exceeds 5 years and Heineken does not plan on investing in another conveyor system within these 5 years, then investing in a smart conveyor would be beneficial if a warehouse runs seven days a week. However, the investment costs of the smart conveyor in Table 18 are assumptions, it is then likely that these costs are higher which would increase the time period. Relying on these assumptions and calculations, the shortest payback period for smart conveyors (for a warehouse running seven days a week) would be 57 years according to Equation 2, which does not constitute a valid business case.

Smart conveyor versus forklift

Table 23: Cost for a smart conveyor of 20 meters

Subject	Description	Smart conveyor (20 meters)
Investment costs	# of turning station	2
	Cost turning station	€ 50,000
	Total cost turning station	€ 100,000
	Straight conveyor (meter)	18
	Cost/meter conveyor	€ 12,500
	Total cost straight conveyor	€ 225,000
	Investment conveyor	€ 325,000
	Installation costs	€ 97,500
	Total investment costs	€ 422,500
5 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 32,500
	Salary	€ 3,343
	Energy	€ 63,625
	Total yearly cost	€ 99,468
6 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 32,500
	Salary	€ 4,011
	Energy	€ 76,350
	Total yearly cost	€ 112,861
7 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 32,500
	Salary	€ 4,680
	Energy	€ 89,075
	Total yearly cost	€ 126,255

Smart conveyors could also be used to replace forklifts. To evaluate the efficiency of smart conveyors compared to forklifts, different distance ranges (5, 20, 50, and 100 meters) were selected. The cost for smart conveyors of 20 and 100 meters are calculated in Tables 23 and 24. The cost for smart conveyors of 5 meters (Table 36) and 50 meters (Table 37) can be found in Appendix A.1. This allows seeing that the longer the distance the conveyor should be able to travel, the higher the initial investment and yearly costs will be.

Table 24: Cost for a smart conveyor of 100 meters

Subject	Description	Smart conveyor (100 meters)
Investment costs	# of turning station	2
	Cost turning station	€ 50,000
	Total cost turning station	€ 100,000
	Straight conveyor (meter)	98
	Cost/meter conveyor	€ 12,500
	Total cost straight conveyor	€ 1,225,000
	Investment conveyor	€ 1,325,000
	Installation costs	€ 397,500
	Total investment costs	€ 1,722,500
5 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 132,500
	Salary	€ 16,714
	Energy	€ 318,125
	Total yearly cost	€ 467,339
6 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 132,500
	Salary	€ 20,057
	Energy	€ 381,750
	Total yearly cost	€ 534,307
7 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 132,500
	Salary	€ 23,400
	Energy	€ 445,375
	Total yearly cost	€ 601,275

The salary of the maintenance is essentially the same as the one calculated in Table 19. Indeed, this table displays the salary of maintenance for 10 meters of smart conveyor, thus for the calculations of the different lengths this was simply divided or multiplied. The energy used for the different lengths of smart conveyors is calculated in Table 25. The investments and yearly costs for a forklift can be found in Table 12.

Table 25: Energy use for different lengths of smart conveyor

Subject	Description	5 meters	20 meters	50 meters	100 meters
Consumption	Energy consumption (ratio)	0.84	0.84	0.84	0.84
	Consumption per meter [kWh]	2.52	2.52	2.52	2.52
	# of meters	5	20	50	100
	Consumption per conveyor [kWh]	12.60	50.40	126.00	252.00
Costs	Cost per kWh	€ 0.21	€ 0.21	€ 0.21	€ 0.21
	Total cost/hour	€ 2.65	€ 10.60	€ 26.51	€ 53.02
	Total cost/year (5 days/week)	€ 15,906	€ 63,625	€ 159,062	€ 318,125
	Total cost/year (6 days/week)	€ 19,087	€ 76,350	€ 190,875	€ 381,750
	Total cost/year (7 days/week)	€ 22,269	€ 89,075	€ 222,687	€ 445,375

To calculate the efficiency of smart conveyors compared to forklifts, it is estimated that a forklift can handle alone the different distances that will be evaluated. Moreover, it is known that a forklift driver can handle approximately 300 pallets in one shift (8 hours). Furthermore, conveyors travel at about 0.45 meters per second [76], and smart conveyor travel at the same speed [45]. The time necessary for smart conveyors to travel the given distance is listed in Table 26.

Table 26: Smart conveyor time per distance

Distance (meters)	Time (sec)
5	11.11
20	44.44
50	111.11
100	222.22

It is also possible to know how many pallets can fit on each of the lengths of the smart conveyor. In its European warehouses, Heineken uses UK and EURO size pallets, that are 100x120cm and 80x120cm respectively. The dimension used for the calculation is that a pallet is always 120cm wide. Moreover, on the smart conveyor, the space between the pallets is estimated at approximately 0.5 meters, but this could be more or less. Thus, the total space necessary for a pallet is 1.7 meters. Consequently, the capacity of each of the smart conveyor lengths is displayed in Table 27.

Table 27: Smart conveyor capacity per distance

Distance (meters)	# of pallets
5	2
20	9
50	29
100	58

This information gives the possibility to evaluate the efficiency of smart conveyors over a full shift. Indeed, when looking at a length of 100 meters, the conveyor needs about $222.22 + 222.22 \approx 450$ seconds to do a full rotation which is equivalent to 8 full rotations per hour. During a full rotation, the place available on the smart conveyor is equal to two times the length of the distance traveled, thus 200 meters. This means that during one full rotation, two times 58 pallets can be moved. Thus, in one hour $8 \cdot 116 = 928$ pallets can be moved. Over a shift of 8 hours, 7,424 pallets can be moved, which makes the capacity of the smart conveyor more than 20 times bigger than the one of a forklift considering that it handles 300 pallets in one shift. This demonstrates the large handling capacities of smart conveyors which would be interesting to investigate further in the case that the production line reaches this production speed.

Table 27 shows that the longer the smart conveyor is, the more efficient it becomes since its capacity increases with its length. Differently for the forklift, the longer the distance to travel is, the less efficient it becomes since its capacity to handle pallets diminished accordingly and its traveling speed does not increases. Thus, depending on the complexity of the operations, the layout of the warehouse, but also of the distance to travel, the business case for the choice of a forklift or a smart conveyor necessitates more specific information.

Evaluation overview

At Heineken, internal transportation and scanning processes are low-variety-high-volume processes which means that the degree of automation of this process tends to be more automated. The evaluation of the three material handling technologies revealed that only AGVs could potentially be implemented. Indeed, AMRs present technical defaults which would make their use impossible to transport the type of load that Heineken does. Furthermore, smart conveyor systems are simply globally too expensive when compared to the conveyors that are already used by the company. AGVs represent the true advantage of reducing labor costs, which is especially an advantage for OpCos in the scope of this thesis. It gives this technology a certain advantage since as can be seen in Figure 12, labor costs represent the largest yearly expense.

Table 28: Material handling innovations' evaluation

Features	AGVs
Degree of automation	High
Scalability	Low
Coupling	Tight
Quality (Compared to the method it replaces)	Improved
Speed (Compared to the method it replaces)	Decreased
Dependability (Compared to the method it replaces)	Improved
Flexibility (Compared to the method it replaces)	Decreased
Cost (Compared to the method it replaces)	Decreased
Payback	< 3 years

4.2.2 Scanning methods

Scanning systems also have an important role in warehousing since they pace the movement of products within the warehouse. Manual scanning systems are managed by humans, which means that their use can be unpredictable. However, automatized barcode scanning methods comply with their programming. Therefore, spending time on superfluous steps is the synonym for decreasing efficiency, especially if automated and more predictable options are available.

Automatic barcode scanner

The step of barcode scanning is always done before or after the transportation of goods. With an automatic barcode scanner, the idea is to combine the transportation and scanning steps by allowing the material handling system used and its load to drive under a gate or beside a pall to automatically scan the visible barcodes. Some advantages of this technique are the evident improvement in efficiency, the reduction of human error, the real-time tracking of products, and the fact that it is scalable and can easily get integrated into existing systems. Some disadvantages are also to be found: the dependability on the barcode quality and position, the limited scanning range, and the maintenance and support that automated systems require [50], [48], [49].

Automatic barcodes scanner present a limitation that restricts their application in Heineken warehouses. The scanning gates and palls scan only the surfaces that are in their range of vision. Therefore, they are only able to scan the sides and/or top of the pallet. This can be seen in Figure 11, 12, and 13 which are an illustration of the three automatic barcode scanners that were previously discussed in Section 3.2.2. However, at Heineken, barcodes are placed on one of the sides of the pallets and some of the forklifts are loaded with a width of three pallets. Moreover, even if a forklift would be charged with two pallets width, the barcode might only be visible on the front side of the pallet. These cases would make the scanning of the barcodes impossible, and the process inefficient.

Figure 11: Docktrack pallet - Vimaan

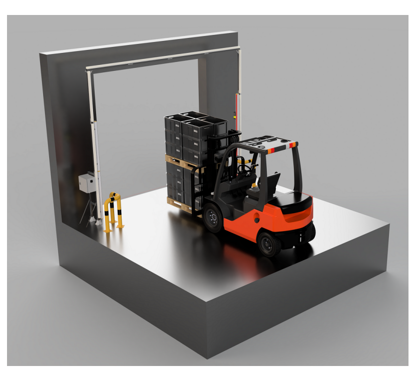

Figure 12: SmartGate - AIT

Figure 13: Pallet scanning - Cognex

Radio Frequency Identification

Similarly to the automatic barcode scanner, RFID sensors can be used for pallet recognition. RFID sensors are to be integrated into pallets and with the use of sensors, tags can be recognized. Therefore, human error is also diminished. So, with the use of this technology, barcodes are not necessary anymore. Moreover, the range of RFID sensors is large enough which makes pallet recognition efficient. Plus, the environment in which they are used is not important since they are not sensitive to dirt or dust [55] [77]. RFID technology is scalable since it can handle larger volumes, adapt to different ranges, and integrate with existing systems [53]. The disadvantages of this innovation involve the continuous cost of integrating tags into each pallet as well as the cost of the machine to put them on; and a certain concern regarding privacy and security due to unauthorized access or data interception.

Figure 14: Pallet labeller [78]

The implementation of RFID tags would engender an increase in the costs of the production process. This is due to the necessity to integrate a pallet labeling machine (Figure 14) for finished goods pallets at each end of the production lines. The cost of one of these machines is between €80,000 to €100,000. In a warehouse such as Zoeterwoude, where ten production lines can be counted, the implementation of the RFID tags as a scanning method would lead to expenses starting at €800,000. Moreover, the tags that are placed on the pallets cost about €0.10 for each pallet, which would very slightly increase the cost per pallet of this sum of money. The cost of this change would drastically increase the cost of the production process and is consequently not improving its efficiency.

Image recognition

A ceiling camera for stock counting, which can be seen in Figure 15, also replaces the process's scanning step. Different advantages are highlighted such as the automatic data collection from the ceiling, the reduction of labor costs, the time-saving quality, the reduction of costs, the gain of transparency as well as the scalability of the innovation since it exports to the WMS after installation [57].

Figure 15: doks recognition unit [57]

In order to find out the amount of time that can be saved by image recognition, some information about the scanning is needed. The constants within the scanning process are given in Table 29.

Table 29: Scan constants

Topic	Abbreviation	Assumption	Source
Time per scan	T_{scan}	5sec	Company's information
Scan per pallet	Scans_{pallet}	2	Company's information
Pallet per shift	Pallets_{shift}	300	Company's information
Shift per day	Shifts_{day}	3	Company's information
Weeks per year	Weeks_{year}	52	Company's information
Salary per hour (maintenance)	Salary_{hour}	€60/h	Company's information
Software installation		€300,000	Indication
Installation cost		30% of the initial product cost	Company's data
Maintenance cost		10% of the initial product cost	Indication

Using a part of this information, the total time needed to scan a pallet can be calculated using Formula 4.

$$T_{pallet} = T_{scan} \cdot Scans_{pallet} = 10s \tag{4}$$

Using the total time needed to scan a pallet and the given amount of pallets that are moved during a shift, the total scan time per shift is calculated using Formula (5).

$$T_{scan,shift} = T_{pallet} \cdot Pallets_{shift} = 3000s = 50min \tag{5}$$

Now all information is provided to calculate the total time saved using image recognition. Besides, the potential money that can be saved on salary due to the saved time on scanning is also calculated. Table 30 shows the saved time for the different amount of working days per week and the saved money for these saved hours. These yearly savings apply as well with both other innovative scanning methods discussed in this section.

Table 30: Yearly savings per production line

	5 days/week	6 days/week	7 days/week
Shifts per week [-]	15	18	21
Scanning time per week [min]	750	900	1,050
Saved time per year [h]	**650**	**780**	**910**
Money saved per year	**€24,375**	**€29,250**	**€34,125**

The money saved per year per production line reflects the actual money spent on scanning each year considering that the warehouse runs non-stop for five, six, and seven days. So if scanning is replaced by image recognition cameras, there would be 650, 780, and 910 hours "free" per year per production line depending on the number of days open. This could be a gain of money since the forklift driver could be formed to do another task during the first or last 50 minutes of his shift for example.

As an example, the warehouse of Zoeterwoude has ten production lines, and therefore, the amount of time and money saved per year can be multiplied by ten since we consider the whole warehouse and not only one production line. Thus, depending if the warehouse runs five, six, or seven days a week the financial savings will be as high as €243,750, €292,500, and €341,250 respectively.

On the other hand, it is also possible to determine the potential extra pallets that can be moved during a shift. Right now this amount is 300 pallets per 8 hours, but within these 8 hours, 50 minutes are used for scanning. The formula 6 shows the active working time during these 8 hours in which there is no scanning.

$$T_{active,shift} = T_{total,shift} - T_{scan,shift} = 430min \tag{6}$$

This means that within 430 min, 300 pallets are transported. The formula 7 shows the possible amount of pallets that could be moved per shift without scanning.

$$Pallets_{shift,new} = \frac{T_{total,shift}}{T_{active,shift}} \cdot Pallets_{shift} = 335pallets \tag{7}$$

Therefore, without scanning the throughput of pallets per 8 hours can be increased by 35 pallets if scanning is not needed anymore. When coming back to the example of Zoeterwoude, an increase of 35 pallets per shift, and this for each production line; would result in a throughput increase of 350 pallets per shift.

This solution is doable under certain conditions. Indeed, in order to increase the throughput of pallets by 350 per shift, the production lines need to be able to increase the speed of production. Moreover, this increase in speed needs to be profitable. Thus, it is important to know whether the extra pallets produced would have good market value, or if they would result in overproduction.

Table 31 illustrates the initial costs for image recognition cameras implementation, as well as the yearly costs depending if the warehouse runs for five, six, or seven days a week. To calculate the number of cameras necessary, the Heineken warehouse of Zoeterwoude has been taken as a study case. However, the number of cameras necessary is only an indication since the surface of the warehouse has not been closely looked up.

Table 31: Initial costs for image recognition

Subject	Description	Image recognition
Investment cost	Cost per recognition unit	€ 610
	Maximum coverage for 1 unit	1,500
	Surface area Zoeterwoude	40,000
	# of unit necessary	27
	Software	€ 300,000.00
	Installation cost (for 27 units)	€ 4,880
	Total investment cost	€ 321,147
5 days/week		
Yearly cost	Maintenance costs (equipment etc)	€ 1,627
	Salary	€ 2,215
	Energy	€ 350
	Total yearly costs	€ 4,192
6 days/week		
Yearly cost	Maintenance costs (equipment etc)	€ 1,627
	Salary	€ 2,683
	Energy	€ 420
	Total yearly costs	€ 4,730
7 days/week		
Yearly cost	Maintenance costs (equipment etc)	€ 1,627
	Salary	€ 3,120
	Energy	€ 490
	Total yearly costs	€ 5,237

Table 32 gives an indicator of the energy use for the different numbers of active days per week. It was assumed that one AI-equipped camera uses 0.01kW/hour, using this as a base, the different values are calculated.

Table 32: Energy use for Image recognition

Subject	Description	Image recognition
kW/year/camera	5 days/week	62
	6 days/week	75
	7 days/week	87.36
Costs	1 kWh	€ 0.21
	Total/year (5 days/week)	€ 350.11
	Total/year (6 days/week)	€ 420.13
	Total/year (7 days/week)	€ 490.15

Table 33 describes the way that the salary for the maintenance of the image recognition cameras is calculated. It is estimated that one operator for one hour per week is necessary to maintain the performance of the cameras if the warehouse uses them seven days per week.

Table 33: Salary costs for image recognition

Subject	Description	Image recognition
Maintenance	Hours/week (5days/week)	0.71
	Hours/week (6days/week)	0.86
	Hours/week (7days/week)	1
	Weeks/year	52
	Salary/hour	€ 60.00
	Total/year (5 days/week)	€ 2,215.20
	Total/year (6 days/week)	€ 2,683.20
	Total/year (7 days/week)	€ 3,120.00

Tables 31 and 32 are used in the following equation to calculate the payback period of image recognition cameras, depending on the number of days the warehouse would run.

Table 34 gives an indication of the payback period for investing in image recognition cameras while the warehouse runs five, six, and seven days respectively, and fifty-two weeks per year, non-stop. The payback period was calculated using Equation 2. The expected return on investment calculated previously, can be found in Table 30. To this one, the yearly cost depending on the number of days during which the warehouse runs are subtracted.

Table 34: Payback period for image recognition cameras

# days	Payback period (years)
5	1.34
6	1.12
7	0.96

The payback period found for the implementation of image recognition cameras makes this innovation a very attractive solution for the company. Indeed, regardless of the number of days during which a warehouse such as Zoeterwoude runs, the payback period stays short and thus, the investment looks valuable. Nonetheless, it does not have to be forgotten that all these calculations rest on assumptions. Here the main cost driver of the innovation is the price of the installation of the software. Yet, this price could be lower than estimated, which would give another outcome.

Evaluation overview

Table 35: Scanning innovations' evaluation

Features	**Image recognition**
Degree of automation	High
Scalability	High
Coupling	Tight
Quality (Compared to the method it replaces)	Improved
Speed (Compared to the method it replaces)	Increased
Dependability (Compared to the method it replaces)	Improved
Flexibility (Compared to the method it replaces)	Increased
Cost (Compared to the method it replaces)	Decrease
Payback	< 2 years

In the different scanning technologies that were found, only the image recognition cameras seemed to be applicable to Heineken's warehouses. Indeed, the automatic barcode scanner revealed some technical difficulties to be able to locate all the barcodes in one or multiple pallets while these are loaded on the forklift. Then, the

RFID sensors solved this problem since there was no visual contact necessary to be able to "scan" the pallet. However, the huge costs of the machine necessary for the application of these sensors, discourage any further research since the application of this technology will only increase costs. Finally, image recognition cameras are a promising technology that overall improves the process when compared to hand scanning methods. Their implementation seems financially a real game changer for the company due to their very low payback period and their qualities improving the at every level.

5 Discussion, conclusion, recommendations, and future research

This section wraps up this thesis and will aim to give an overview of the findings and conclude by giving recommendations to Heineken as well as directions for future research.

5.1 Discussion

This section is used in order to review explanations and interpretations results found in the earlier section on this thesis question and literature review. Implications, acknowledgment, and assumptions are reviewed.

5.1.1 Section 2

To begin with the discussion of this thesis, Section 2.2 aims to analyze the KPIs of Heineken. For this analysis, five references have been used in order to have an overview of the KPIs used in the literature. Furthermore, the challenge was also to find relevant literature. Indeed, there were very few documents available for the FMCG industry, or not too outdated and giving the information that was necessary namely a KPIs list. Five texts were selected for this section based on specific criteria: timeliness, diversity of authors, relevance to warehouse management, performance indicators, and productivity measurement. All aimed to compile a list of KPIs used in warehouse management. More content was available on non-academic websites, but since these were not peer-reviewed or did not have an academic background, they were not used.

5.1.2 Section 3

Then, in Section 3.1 the research of the process using the most labor should originally have been made by studying the data of BCS. However, after beginning the investigation, multiple limitations appeared. Indeed, the KPIs that are being reported on BCS are lacking precision, meaning that the exact process using the labor cannot be found using these KPIs. Plus, the KPIs are reported under different names depending on the Opcos or sites they are being filled in by. This leads to unnecessary complexity for data retrieving and understanding. Another point is that all information about outsourced personnel from LSP is not reported on BCS. In addition, the regularity of reporting KPIs values is low which illustrates a certain negligence on this side. This makes the reading, analysis, and understanding of the data very challenging overall. Appendix **??** illustrates this situation with a table made to analyze the division of the personnel in European warehouses. It can be seen that the KPIs are different per OpCo or per site whereas they should be reporting the same information. Moreover, it can also be seen that some data are missing which could decrease the exactitude of the analysis.

5.1.3 Section 4

In section 4, multiple assumptions have been made for the good run of the calculations. Indeed, the installation costs have been estimated to be 30% of the cost of the technology itself. This number was found in a document shared by Heineken as explained in Section 4.2.1. The yearly maintenance costs have been estimated as being equal to 10% of the cost of the technology itself. Continuing regarding maintenance, it was assumed to stay the same regardless if the warehouse runs for five, six, or seven days a week. The salary cost of the maintenance per hour is assumed to be the same (€60/hour), whatever technology is looked up. However, this could change since increasing the level of automation of an operation also signifies increasing the complexity of the systems used. Moreover, the gross personnel cost per employee is of €39 and the assumption is made that every employee cost the same regardless of the length of service in the company, or of the number of sick days that he took in a year for example. To finish with the general assumptions for this section, the energy price considered is the one at the time this thesis is written. All these assumptions were made in order to have a base to make the calculations. A particularly difficult limitation here was the inability to access relevant financial data about the different innovations. Being assumptions in this thesis, their values could vary. For all of them (maintenance, energy, and installation) expected the estimation of the cost of a forklift driver, the modification of the value would influence the calculation of both technologies (new and old) which would not make a difference in the result. To finish, in no calculations were downtime, peak period, accidents, or other hazards have not been taken into consideration.

Material handling systems

For the calculation of AGVs versus forklifts, the rule of thumb that one forklift is replaced by three AGVs is used. This is because at the moment AGVs are moving approximately three times slower than forklifts. However, it would be possible that in the future, the navigation speed of AGVs increases and that this rule of thumb does not hold anymore. This would be only favorable to the adoption of AGVs since they would be able to work faster, and consequently, fewer of them would be necessary. Moreover, the cost of one AGV has been estimated at €125.000 but this is also a variable value since there exist different types of AGVs more or less new, and more or less options. A lower price for the AGV would lead to a more interesting investment, whereas a higher price to the opposite. If the yearly cost of a forklift driver would increase, the AGV system would become even more profitable, and reciprocally the opposite scenario would happen if the yearly cost of a forklift driver would come to decrease. The yearly energy consumption of a forklift in a year has been calculated as an average of the total yearly consumption of multiple forklifts on the basis of full-time running (24/7). These data are considered to be representative of all Heineken warehouses.

For the calculation of smart conveyors, the cost for smart turning stations is estimated to be the same as for basic conveyors, and the cost for the straight conveyor is estimated 25% more expensive than for basic conveyors. Moreover, the maintenance salary used for conveyors and smart conveyors is assumed to be the same. These assumptions are relative and could differ. However, since conveyors and smart conveyors are using both the same assumptions, the results stay representative of reality. Another assumption states that the energy consumption per meter of conveyors is 3kWh. Using the findings in the literature, the energy consumption of smart conveyors is estimated to be 16,05% lower. In addition, this consumption is regardless of the type of conveyor, its existence, or the load it transports. All these elements could impact the use of energy. Therefore, the research could have been more precise while taking these elements into consideration.

Scanning methods

On the side of scanning methods, the automatic barcode scanner solution presents some limitations that excluded it from the investigation. They can only scan on top and on the side of the forklifts, however, the barcodes can also be situated on the front. This failure means that the automatic barcode scanner is not able to visually reach every surface that has a barcode and is consequently not efficient enough to be used in Heineken's warehouses. Moreover, if the implementation was possible for certain processes (using only two pallets wide loading), the fact that the forklift always must drive under this gate could potentially decrease the efficiency of the routing of the forklifts in the warehouses. Another effect could be a decrease in safety in the warehouse if too many forklifts would happen to be at the same place and at the same time while wanting to pass the scanning points.

Finally, the implementation of image recognition cameras to replace hand scanning has been investigated, using the following assumptions. The cost of the implementation of the software has been roughly estimated at €300,000 and this could of course take different values. A change in the value of the implementation of the software system would impact the outcome of these calculations since it is one of the main drivers regarding the investment cost. Moreover, similarly, as for the calculation for the material handling systems, the yearly maintenance and installation costs have been assumed to be respectively equal to 10% and 30% of the cost of the product itself. The energy consumption for a camera is estimated at around 10W per hour, which could vary depending on the type of camera. In addition, the number of units necessary has been calculated as an approximation based on the surface area of a warehouse, consequently, it is possible that a few more cameras are in fact required. It is also known that approximately 300 pallets come out of the production line every shift, thus it has been estimated that a forklift driver needs to scan two times these 300 pallets each shift, namely when they go to production and when they leave it. The time necessary to scan one pallet is assumed to be of five seconds.

5.2 Conclusion

In this section, the main research question as well as the different sub-questions that were stated in Section 1.3 will be answered.

5.2.1 Research question

At Heineken, continuous improvement is ingrained in the company culture, driving success and shaping employees' working lives. They actively pursue growth opportunities and efficiency improvements in their warehouses, recognizing that technological advancements often yield new warehousing solutions. In the ever-evolving warehousing industry, the challenge lies in staying receptive to change and remaining aware of emerging ideas and solutions. Competitiveness is essential for companies as it ensures customer satisfaction, fosters growth, and maintains relevance and credibility within the industry. The research question for this thesis is:

"How can warehousing trends and innovations improve the performance of Heineken's processes in Europe?"

5.2.2 Sub-questions

1. *How does Heineken measure its warehouse performance?*

   a) *What KPIs does Heineken use to measure the warehouse performance?*

   Heineken measures the performance of its warehouse according to a list of KPIs that each site needs to fill in at a specific frequency. Their KPIs are distributed according to the vision of the company which divides them into four categories. A total of forty-nine KPIs are listed and divided where ten of them are mandatory and the rest is optional.

   b) *Which KPIs are in the literature relevant to measure warehouse performance?*

   In theory, KPIs are mainly divided into cost, productivity & utilization, quality, and time categories. In the theory, KPIs for each category were found, however, it was observed that the most recurrent ones were from the productivity & utilization category. The case studies revealed a shift in the primary interest of companies, which went from reducing costs to increasing customer satisfaction. It was found in theory that each category needs to be taken into account, and the study cases showed the shift of the industry for an improvement of the quality.

   c) *How can Heineken's KPIs be evaluated?*

   The evaluation of Heineken's KPIs revealed a focus of the company in the field of productivity & utilization while still measuring the performance in the three other categories stated earlier. Moreover, the number of mandatory KPIs is relevant to the findings in the literature. In the same way, as the company studied in the case study, but differently than in the literature, Heineken has a mandatory KPI related to warehouse safety, which is a sign of a certain responsibility toward well-being while working. Finally, from the findings in the study cases, the evaluation of Heineken's KPIs lead to conclude of a lack of mandatory measurement regarding the quality of the operations in logistics.

2. *What trends and innovations improve the performance of warehouse processes?*

   a) *Which processes use the most labor in the internal warehouses of Heineken?*

   In Heineken's European warehouses, labor cost is one of the main expenses to support. After researching the database of the company, it was found that internal transport employs the most labor in the warehousing unit. However, there were no further details about the precise process. Thus, the internal transport flow having the capacity to deal with changes has been selected. Consequently, the production side of the operations (feeding the lines, discharging the lines, and storing finished products) was selected due to its stability.

b) *What are the new technologies improving the performance of these warehouse processes?*

   The process selected is made of two steps; namely transporting the pallets and scanning them. For both steps, three trends and innovations were researched in the literature. The findings lead to the investigation of AGVs, AMRs, and smart conveyors for material handling methods. For the scanning methods, the technologies that were found are automatic barcode scanners, RFID tags, and AI cameras. All the methods found aimed at automation, and unmanned operations.

3. *What innovations are fitting Heineken's processes?*

   a) *How to evaluate the different options to Heineken's processes?*

   In the literature, various measurement criteria are identified as objectives to take into account while evaluating innovations. These criteria consider the innovations' fit, impact, and financial value to the company. The fit of the innovation aims to overview whether the technology is made for the type of process that is considered. The impact refers to the way in which the innovation will influence the quality, speed, dependability, flexibility, and cost of the operation. Finally, the financial value takes into consideration the payback period generated by the investment in the technology.

   b) *What are the most attractive options to implement?*

   After investigating each potential solution further, some were revealed as not applicable to the warehouse process of Heineken. Different reasons were found, such as a too-high cost, or technical limitations. On the side of material handling systems, only AGVs seem to be good to implement; and on the side of scanning methods, AI cameras are definitely an option that needs to be looked into.

5.2.3 Answer to the research question

The answer to the sub-questions previously facilitates a clear explanation of the research question. Warehousing trends regarding the KPIs choice showed a certain focus on quality KPIs. This is the category where Heineken only has one KPI. Knowing about the trend is important for Heineken since it will allow them to review their quality KPI and evaluate whether it is sufficient to measure all aspects of the performance in this category. This could lead to identifying new areas where the performance is lacking and consequently improving them. Furthermore, warehousing trends and innovations tend to improve the performance of processes by proposing automated and unmanned solutions. They tend to minimize the necessity of humans for recurrent tasks in warehouse processes. This is an improvement of the performance that was particularly researched during this thesis since the cost of labor is very extensive for European warehouses situated in countries with high wages. The outcome of this research put automation in warehouses as a point of interest to improve performance. More specifically, AGVs as material handling methods and image recognition cameras as scanning methods stand out.

5.3 Recommendations

Based on the research made during this thesis and on the previous conclusions, here is a list of recommendations for Heineken.

a) In order to be more in line with the industry trends regarding the type of KPIs used, it would be wise to investigate further into quality KPIs for logistics and evaluate whether any of them should be added.

b) Regardless of the number of days a warehouse is open, the implementation of AGVs seems very promising for the company. To improve the performance of material handling systems, investigating into AGVs is the right thing to do.

c) Even if they are not yet applicable, AMRs have attractive qualities that keep maturing. It would be good to stay alert about this topic.

d) Image recognition seems to be a very beneficial innovation. Their implementation should be seriously considered to improve the speed of operations.

5.4 Future research

In this section, multiple ideas for future research are described.

a) A more extensive study regarding KPIs trends in the FMCG industry.

b) Study deeper the potential of AGVs by doing a benchmark of the different AGVs options available on the market, as well as the different suppliers.

c) Image recognition is looking like a revolutionary scanning method, thus diving in deeper about their abilities, getting an overview of the market options as well as more financial insight is a good idea.

d) If hand scanning disappears, 50 minutes is saved over an operator's shift. Then, internal research about what tasks he could be doing during this time would be good preventive research.

e) Still concerning the automation of the scanning step, it would mean that more pallets could be handled per shift. Therefore, investigating whether this increase is technically possible, but also whether higher productivity would stay profitable is surely of interest.

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A Appendix

A.1

Table 36: Cost for a smart conveyor of 5 meters

Subject	Description	Smart conveyor (5 meters)
Investment costs	# of turning station	2
	Cost turning station	€ 50,000
	Total cost turning station	€ 100,000
	Straight conveyor (meter)	3
	Cost/meter conveyor	€ 12,500
	Total cost straight conveyor	€ 37,500
	Investment conveyor	€ 137,500
	Installation costs	€ 41,250
	Total investment costs	€ 178,750
5 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 13,750
	Salary	€ 836
	Energy	€ 15,906
	Total yearly cost	€ 30,492
6 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 13,750
	Salary	€ 1,003
	Energy	€ 19,087
	Total yearly cost	€ 33,840
7 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 13,750
	Salary	€ 1,170
	Energy	€ 22,269
	Total yearly cost	€ 37,189

Table 37: Cost for a smart conveyor of 50 meters

Subject	Description	Smart conveyor (50 meters)
Investment costs	# of turning station	2
	Cost turning station	€ 50,000
	Total cost turning station	€ 100,000
	Straight conveyor (meter)	48
	Cost/meter conveyor	€ 12,500
	Total cost straight conveyor	€ 600,000
	Investment conveyor	€ 700,000
	Installation costs	€ 210,000
	Total investment costs	€910,000
5 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 70,000
	Salary	€ 8,357
	Energy	€ 159,062
	Total yearly cost	€ 237,420
6 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 70,000
	Salary	€ 10,029
	Energy	€ 190,875
	Total yearly cost	€ 270,903
7 days/week		
Yearly costs	Maintenance costs (equipment etc)	€ 70,000
	Salary	€ 11,700
	Energy	€ 222,687
	Total yearly cost	€ 304,387

A.2

Table 38: AGVs and forklifts costs for 10 years

	5 days/week		6 days/week		7 days/week	
year	AGV	Forklift	AGV	Forklift	AGV	Forklift
1	€ 563,785	€ 357,183	€ 573,117	€ 406,645	€ 582,356	€ 456,075
2	€ 647,571	€ 614,367	€ 666,235	€ 713,290	€ 684,711	€ 812,151
3	€ 731,356	€ 871,550	€ 759,352	€ 1,019,935	€ 787,067	€ 1,168,226
4	€ 815,141	€ 1,128,733	€ 852,469	€ 1,326,579	€ 889,422	€ 1,524,301
5	€ 898,927	€ 1,385,916	€ 945,586	€ 1,633,224	€ 991,778	€ 1,880,376
6	€ 982,712	€ 1,643,100	€ 1,038,704	€ 1,939,869	€ 1,094,134	€ 2,236,452
7	€ 1,066,497	€ 1,900,283	€ 1,131,821	€ 2,246,514	€ 1,196,489	€ 2,592,527
8	€ 1,150,282	€ 2,157,466	€ 1,224,938	€ 2,553,159	€ 1,298,845	€ 2,948,602
9	€ 1,234,068	€ 2,414,649	€ 1,318,055	€ 2,859,804	€ 1,401,200	€ 3,304,678
10	€ 1,317,853	€ 2,671,833	€ 1,411,173	€ 3,166,449	€ 1,503,556	€ 3,660,753