Economic analysis of a test bench prototype for optical part identification in automotive warehouse logistics

Master thesis

by

Thomas Unger

Graz University of Technology

Faculty of Mechanical Engineering and Economic Sciences

Institute of Business Economics and Industrial Sociology

O. Univ.-Prof. Dipl.-Ing. Dr. techn. Ulrich Bauer

Graz, February 2019

In cooperation with:

Jerich International

EIDESSTATTLICHE ERKLÄRUNG

Ich erkläre an Eides statt, dass ich die vorliegende Arbeit selbstständig verfasst, andere als die angegebenen Quellen/Hilfsmittel nicht benutzt und die den benutzten Quellen wörtlich und inhaltlich entnommene Stellen als solche kenntlich gemacht habe.

Graz, am 18.02.2019

Thomas Unger
……………………………………………………..
(Unterschrift)

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

Graz, 18.02.2019

Thomas Unger
……………………………………………………..
(signature)

Kurzfassung

Die Firma Jerich International ist ein Transport und Logistikdienstleister in den verschiedensten Branchen. Besonders im Automobilbereich möchte das Unternehmen die Auslieferqualität verbessern. Bei dem manuell durchgeführten Prüfprozess der Teile zu den jeweiligen Transportinformationen, kann menschliches Versagen zu einer falschen Etikettierung der Transportbehälter führen. Ein Projekt, mit dem Ziel der Entwicklung einer unterstützenden technischen Lösung für die Qualitätssicherung, ist die Folge. Ein Prüfstand soll mittels Bildverarbeitungssoftware, eine eindeutige Bauteilidentifikation garantieren. Ziel dieser Masterarbeit ist die ökonomische Analyse des Projekts mittels dynamischer Methoden der Investitionsrechnung. Weiters soll eine Analyse der Prozessänderungen, die geplante Implementierung des Prüfstandprototypen optimieren.

Zu Beginn wird das Projekt vorgestellt sowie ein Überblick über die Problematik der falschen Etikettierung gegeben. Die Technologie des Prüfstands wird in Auszügen vorgestellt und die SAP Daten der Lagerverwaltung analysiert. Die Auswirkungen einer optimierten Lagerplatzbelegung werden ausgearbeitet und diskutiert. Es wird ein Mengengerüst erstellt, die Transportwege ermittelt und die Prozesszeiten sowie die Unterschiede der aktuellen und der Zielsituation ausgearbeitet. Vorteile und Nachteile werden aufgezeigt und Eingangsgrößen für die Investitionsrechnung abgeleitet. Besonders die Flächenkosten und die Personalkosten stehen im Fokus der Untersuchung, da hier von der Lagerverwaltung die größten monetären Auswirkungen erwartet werden.

Es folgt eine Kostenaufstellung und das Einsparungspotential der Investition wird aufgezeigt. Die Ermittlung des Kapitalwerts sowie der dynamischen Amortisationszeit bildet den Abschluss der Berechnungen.

Ein positiver Kapitalwert von rund 171.000€ am Ende der 5-jährigen Nutzungsdauer und eine dynamische Amortisationszeit von 2,55 Jahren, indizieren die Vorteilhaftigkeit des Projekts.

Abstract

The company Jerich International is a transport and logistics service provider in various industries. Especially in the automotive sector the company intends to improve delivery quality. During the manual inspection process of the parts to the respective transport information, human error can lead to incorrect labelling of the transport containers. A project with the aim of developing a supporting technical solution for quality assurance is the result. A test bench with image processing software should guarantee a clear component identification. The objective of this master thesis is the economic analysis of the project, using dynamic methods of investment calculation. Furthermore, an analysis of the process changes should optimise the planned implementation of the test bench prototype.

At the beginning, the project is presented and an overview of the problem of incorrect labelling is given. The technology of the test bench will be presented in excerpts and the SAP data of the warehouse management will be analysed. The effects of optimised storage location assignment are worked out and discussed. A quantity structure is created, the transport routes are determined and the process times as well as the differences between the actual and the target situation are elaborated. Advantages and disadvantages are identified and input values for the investment calculation are derived. Especially the area costs and the personnel costs are the focus of the investigation, because here the greatest monetary effects are expected from the warehouse management.

Following a cost statement and the saving potential of the investment is presented. The determination of the net present value as well as the dynamic amortisation period completes the calculations.

A positive net present value of around 171.000€ at the end of the 5-year useful life and a dynamic amortisation period of 2,55 years, indicate the advantageousness of the project.

Table of Contents

1 Introduction

This chapter provides an overview of the content of this master thesis. First the company Jerich International is introduced. In the following, the initial situation is presented as well as the goals and task definition. In addition, the investigation area, the actual inspection process and an overview of the test bench prototype are given. Finally, the target inspection process is presented and compared with the actual inspection process.

1.1 Company Description[1]

The transport and logistics company Jerich was founded in 1969 by Herbert Jerich. He is the Chief Executive Officer (CEO) as well as the 100% shareholder and represents the head of the group Jerich International. Today his son Herbert Jerich Jr is also active in the company and plays a decisive role in its success. In *Figure 1* the founder of the company and his son are shown together in the head office in Gleisdorf.

Figure 1: Herbert Jerich Jr (left) & Herbert Jerich (right)[2]

Jerich International is a global group of companies that offer large-scale trade and industry customers a holistic logistics approach to freight forwarding through global supply chain management. This approach consists of 4 largely comprised service areas:

- Classical forwarding services
- Terminal logistics
- Information and communication technology
- Value added additional services

[1] https://www.jerich.com, viewed on 19.12.2018
[2] source: https://www.jerich.com, viewed on 19.12.2018

Tailored to the needs of the customers and manufacturer, the whole supply chain activities are synchronized. Instead of offering just various terminals, handling and transport services, Jerich International supports from the moment an order is produced by the end customer. The advantage of this concept is that customers can concentrate on production while the logistical tasks are transferred to a professional partner.

As a global company, they work for various industries and sectors with a wide range of specific requirements. Some of the most important industries Jerich International works with, are listed below:

- Paper industry
- Automotive industry
- Steel industry
- Packaging industry
- Beverage industry

At the end of 2018, Jerich International had 18 subsidiaries in Europe and the United States of America. Approximately 800 employees work at 26 different locations with a growing tendency. *Figure 2* and *Figure 3* show the locations where the company operates.

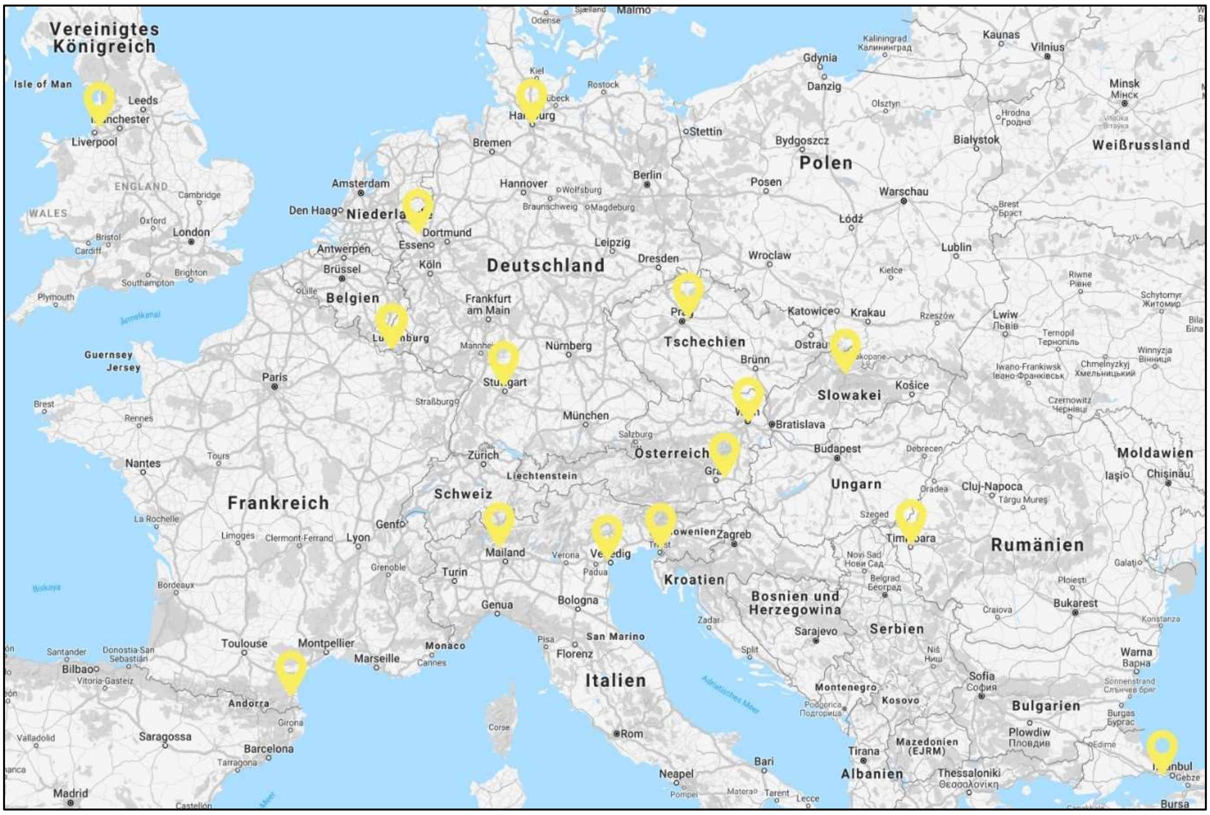


Figure 2: European locations[3]

[3] source: https://www.jerich.com, viewed on 19.12.2018

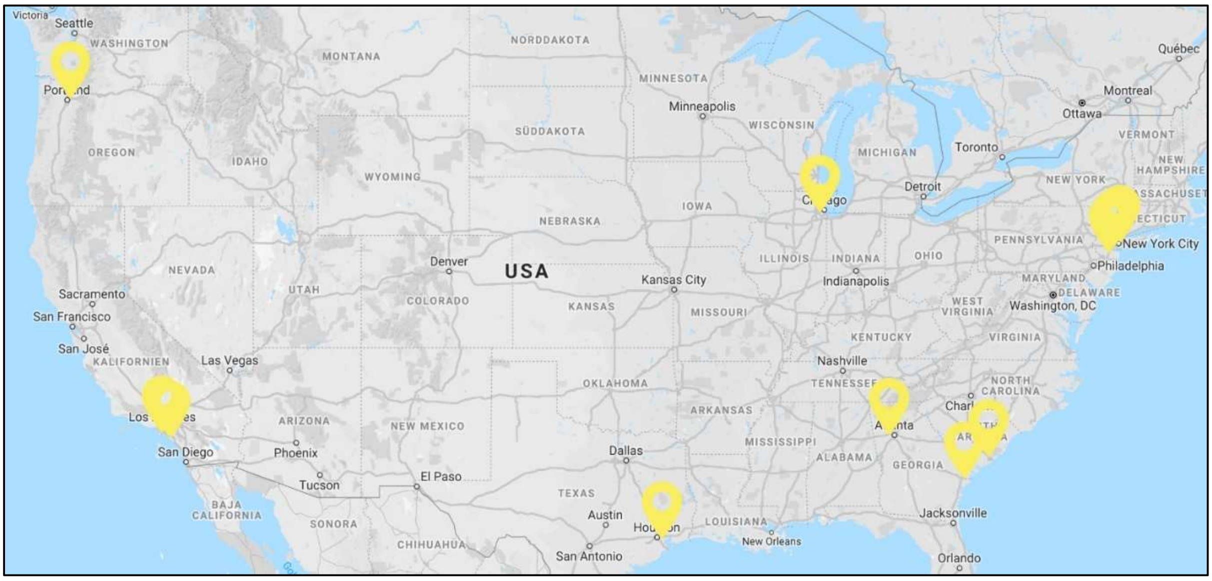


Figure 3: North American locations[4]

1.2 Initial Situation

In this subchapter, the initial situation of this master thesis is discussed. As already mentioned in *chapter 1.1*, the automotive industry is an important market for Jerich International. At this point the following Original equipment manufacturers[5] (OEM) and suppliers should be mentioned as examples, especially for the Graz region in Styria. This list does not represent a complete list of all OEMs or active suppliers in Styria, but companies that are more closely connected to the project dealt with in this paper.

- OEMs:
  - BMW
  - VW
  - Audi
  - Daimler
  - Peugeot
  - Jaguar
- Suppliers[6] :
  - Magna Steyr Fahrzeugtechnik
  - Magna Presstec
  - Magna Heavy Stamping

[4] source: https://www.jerich.com, viewed on 19.12.2018
[5] OEM stands for Original equipment manufacturer. In the automotive sector, this refers to vehicle manufacturers who purchase components for their vehicles from suppliers and resell them under their own brand names
[6] All companies listed here are subsidiaries of Magna International

The automotive industry is subject to high price and quality requirements to remain competitive on the market. For this reason, Jerich International must also continuously optimize its internal processes and quality standards. An important factor in this context is the delivery quality in the sense of the “6-R rule of logistics” (more detailed explanation in *chapter 2.1.1*). If the requirements in the delivery quality are not met, enormous costs can arise for both, the customer and the service provider. At Jerich International, the problem of incorrect labelling of containers is touched upon here. Since a large proportion of deliveries, especially in the automotive industry, are so-called JIT (Just in Time) deliveries, incorrectly filled or wrong labelled containers are a major risk here, which in extreme cases can lead to a temporary standstill of the customer’s production. With that in mind, the CEO Herbert Jerich has decided to invest in quality assurance to counter that risk. Considering important contemporary economic issues, such as digitalization and industry 4.0, a project was started to support the manual activity of quality assurance with an innovative technical solution. Also, the corporate goal of a zero-error strategy is addressed by this project.

The above-mentioned project is named “optical part identification” and was launched in early 2018 in cooperation with ivii. The company ivii is a subsidiary of KNAPP Aktiengesellschaft (AG) and is specialized in the field of intelligent image processing. Furthermore, Bayerische Motoren Werke (BMW) is involved in the project, since in the first step BMW components are used in the development and testing of the prototype test bench for optical part identification. The test bench and its planned implementation are examined more detailed in *chapter 1.8* and *chapter 3.1*.

Jerich International is a family-owned company. Herbert Jerich wants to further expand his company and create the best possible conditions for a long-term and sustainable corporate future. For this reason, the optical part identification project was launched as quickly as possible, which is why detailed investigations into the monetary and process calculation aspects were not given the highest priority at the outset.

As result of this situation, the goals and tasks (more details in *chapter 1.3* and *1.4*) of this master thesis were defined. Parallel to the development of the prototype of the test bench by the company ivii, these goals are elaborated to serve as a supporting decision basis for the implementation of the prototype as well as for a planned small series. Furthermore, Jerich International uses the results of the investment calculation for the budgeting of the business year 2019.

1.3 Goals

Based on the initial situation, the following goals were defined in cooperation with the project management of Jerich International. The overall objective is the economic impact of the project.

At this point it should be mentioned for better understanding that for the implementation of the prototype basically two different processes are considered. In the further course of this work a distinction is made between "Kommi"[7] and "NOT-Kommi". *Chapter 3.1.1* and *chapter 3.1.2* explain these processes and the resulting differences in more detail.

1) Elaboration and analysis of the target process for optical part identification based on the prototype test bench with a defined part scope.

    1. Elaboration of the differences between the actual/target situation:

        - Analysis of the storage location assignment
        - Comparison of the actual/target transport distances
        - Comparison of the actual/target process times

    2. Determination of the impact on the process costs:

        - Determination of the area costs of the test bench
        - Determination of the personnel costs of the target processes

2) Economic analysis of the project based on the prototype test bench and the associated processes.

    1. Determination of the net present value (NPV) of the investment

        - Recommendation based on the result

    2. Determination of the dynamic amortisation period of the investment

        - Recommendation based on the result

The order of the objectives listed above and the related tasks in the next chapter can be interpreted as a guideline for this thesis.

[7] "Kommi" is an in-house abbreviation for the German word "Kommissionierung". The English translation is "Commissioning"

1.4 Task Definition

From the goals defined in *chapter 1.3*, concrete tasks can be derived that lead to the desired results after their completion. Characterized by the numbering, the following tasks can be assigned to the respective objectives.

1) Execution and analysis of the tasks 1a and 1b.

   a) Associated with goal 1a:

      - Analysis of the SAP data of the part scope
        - Process “NOT-Kommi” (~100 different BMW parts)
        - Process “Kommi” (~320 different BMW parts)
      - Development of a quantity structure
      - Optimisation of storage location assignment
      - Creation of the adapted warehouse layout
      - Calculation of the transport distances in Microsoft Excel
      - Calculation of the process times in Microsoft Excel
      - Give an overview of the target situation
      - Give an overview of the target situation

   b) Associated with goal 1b:

      - Estimation of the area costs of the new warehouse layout focused on the prototype test bench
      - Determination of the personnel costs using time study

2) Execution and analysis of the tasks 2a and 2b.

   a) Associated with goal 2a:

      - Creation of a calculation model in Microsoft Excel for the determination of the net present value

   b) Associated with goal 2b:

      - Creation of a calculation model in Microsoft Excel for the determination of the dynamic amortisation period

1.5 Investigation Area

The investigations of this master thesis deal with the terminal Gleisdorf (*chapter 1.6*). Only the automotive area will be investigated with the focus on the warehouse Gate 12 (warehouse Gate 4 is not considered). In warehouse Gate 12 it is possible to differentiate between different customers and processes. For this master thesis, only the containers of the customer BMW are evaluated in the following in-house processes:

- “NOT-Kommi” process
- “Kommi” process

1.6 Headquarter and Terminal Gleisdorf

The project optical part identification is a pilot project for the company Jerich International. After the successful implementation of the prototype into the daily business, a small series of test benches is planned to integrate this new technology step by step at all relevant locations of the company. The prototype will go into test operation at the terminal Gleisdorf. The terminal is located in Pirching in Styria. Because of its immediate proximity to the headquarter, this location is called Gleisdorf terminal within the company. The terminal currently has 64 employees. 10 employees responsible for administrative and office activities and 54 in the warehouses (supervisors, forklift drivers, commissioners…). The turnover of the terminal Gleisdorf in 2018 - for the automotive sector - is approximately 3.600.000€ p.a. In *Figure 4* the headquarter of Jerich International is shown. Only 5 minutes by car is the terminal Gleisdorf which can be seen in *Figure 5*. At this terminal are mainly goods for the paper as well as the automotive industry handled.

Figure 4: Headquarter Jerich International[8]

[8] source: https://www.jerich.com, viewed on 19.12.2018

Figure 5: Terminal Gleisdorf[9]

1.6.1 Warehouse "Gate 12"

The terminal consists of several warehouses. For the part identification project, the focus is on the warehouse "Gate 12"[10], where all locally relevant BMW components are transhipped. In addition, it must be mentioned here that goods for other customers from the automotive industry are also located in this warehouse. A schematic layout of the hall was created with the help of Microsoft Visio[11] to depict the considered processes and the material flow. The basis for the layout in *Figure 6* was a true-to-scale plan (included in *appendix 1*) in Microsoft Excel, which was provided by the management.

The hall extends over the long side (the side where the gates 12-17 are located) with 60 meters and the wide side measures 50 meters. These ~3000 square meters are mostly used for the storage of the transport containers, while the free areas act as the driveways for the forklifts. Only the orange areas marked with "Commissioning" and the two offices serve as secure work area without forklift traffic. The other sectors such as the "Preparation places", the "Goods receipt" and the "Commissioning outgoing" are especially important for the loading and unloading of trucks. The time, in which lorries stand at the loading ramp, should be as short as possible for cost and efficiency reasons. Therefor those areas are placed very close to the gates to keep the transport distances short.

[9] source: https://www.jerich.com, viewed on 19.12.2018
[10] Warehouse „Gate 12" is named after the numbering of the gates for the delivery and collection of goods by trucks. Gate 12 can be found in the upper left of the warehouse layout in *Figure 5*
[11] Microsoft Visio is a diagramming and vector graphics application and is part of the Microsoft Office family

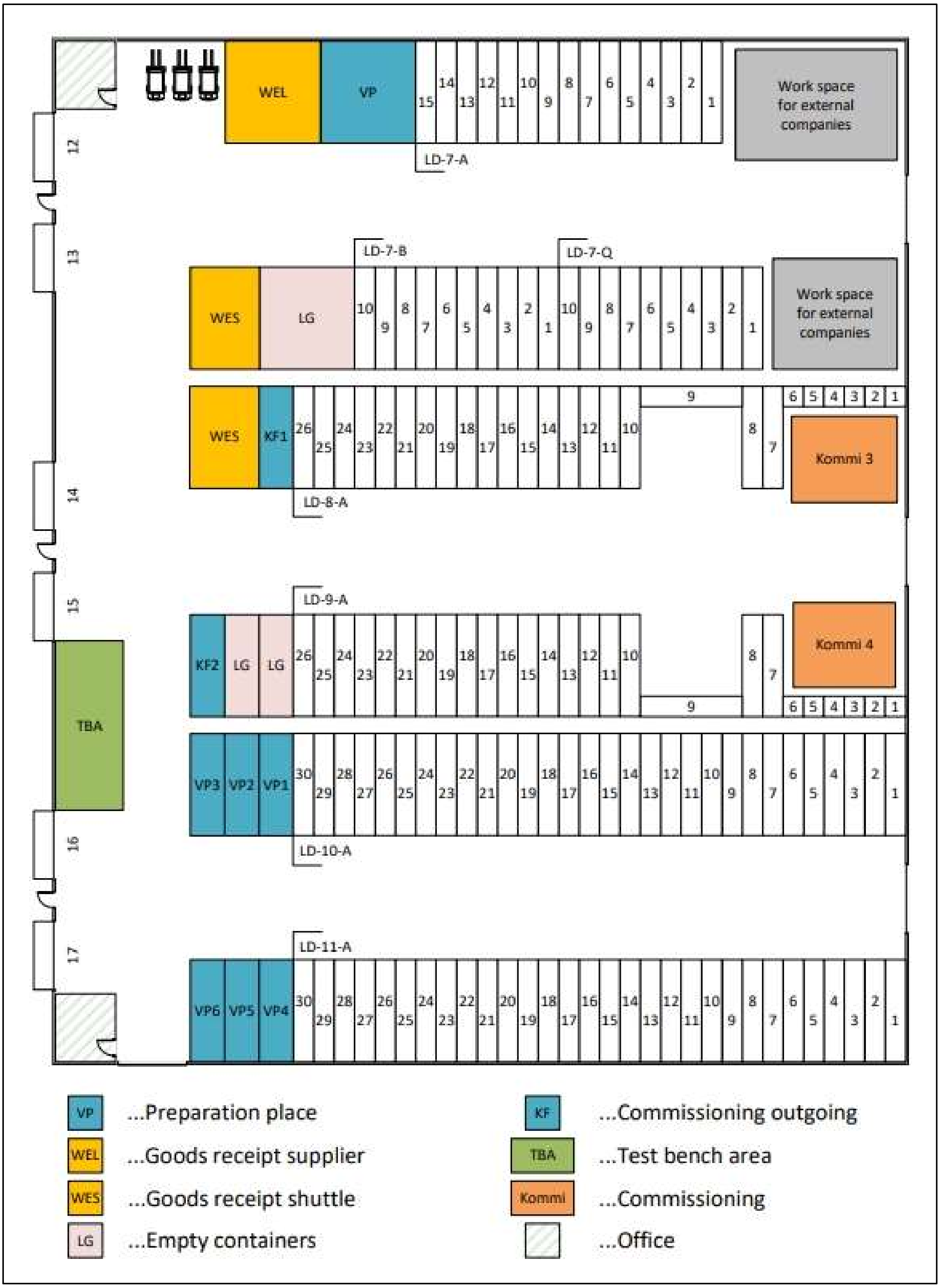


Figure 6: Overview layout Gate 12

At this point it is noted in advance that there is a distinctive difference between the Kommi and NOT-Kommi processes. In the storage series LD-10-A and LD-11-A (location in the warehouse see *Figure 6;* Photo in *Figure 7*), there is no area for empty containers as only goods for the

NOT-Kommi process are handled here. During this process, the transport bin leaves the warehouse with the same content as it was delivered. Due to this fact, no empty containers can be produced here. The test bench area is also highlighted in the overview. Here the prototype will be installed after its completion. The arguments for this location are discussed in *chapter 3.1.10*. In logistics, the type of storage used here is known as block storage[12] in accordance with the First In-First Out[13] (FIFO) principle.

Figure 7: LD-10-A and LD-11-A storage series

1.6.1.1 Transport Containers

To refine the picture of the investigation area, one of the mid-range transport containers is shown in *Figure 8*. Each customer has different bins in terms of main dimensions and design. The largest main dimensions are 1200mm x 800mm x 800mm and when filled they can weigh up to 200kg. All containers are suitable to be transported with forklifts and can be stacked on top of each other. Some are also designed to be used in automated storage facilities.

[12] Block storage is a storage type in which packaging materials are stored without fixed devices, such as shelves, in the warehouse. Goods are stacked in crates or pallets, usually in several layers on top of each other and next to each other. More details in *chapter 2.1.2*
[13] More deatails in *chapter 2.1.2*

Figure 8: Transport container

1.6.1.2 Forklift Truck

All movements of the containers within the warehouse are carried out by forklift trucks (depicted in *Figure 9*). Every driver has a handheld (presented in *Figure 10*) and a packing list. The packing list (shown in *Figure 14*) contains all necessary information for the driver, such as the handling unit number, quantity or storage location. The handheld enables the driver to make bookings in SAP[14] directly from the driver's seat. In addition, barcodes can be scanned to display the contained information. For safety reasons, the forklifts may move a maximum of 3 stacked containers at the same time.

Figure 9: Forklift truck

[14] Enterprise and Resource Planning Software by SAP SE to manage business operations and customer relationships

Figure 10: Handheld

1.7 Actual Inspection Process

The actual inspection process is an important step in the operational value chain. *Figure 11* shows Jerich International's standard process model for the automotive sector.

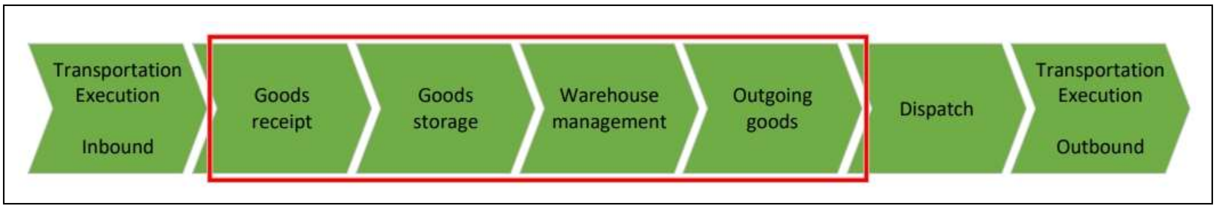


Figure 11: Jerich automotive standard process model[15]

The areas marked in red show the part of the internal material flow at which a clear identification of parts is required. In the future, the test bench for optical part identification will also be used here to support the employees.

[15] provided by Jerich project management; edited by the author

1.7.1 Application Areas

Goods Receipt:

Jerich International takes over the warehousing of parts for customers and thus also the stock responsibility. As soon as goods have been physically and systematically taken over, a shortage can be commercially charged to Jerich International. A complete incoming goods inspection and thus the identification of parts is a prerequisite for 100% stock transparency.[16]

Commissioning:

Commissioning is the compilation of certain articles from a total quantity, provided on the basis of orders. The correct picking requires a clear identification of the ordered article. Errors in the delivery composition can lead to considerable additional costs for Jerich International and its customers. In the standard process model shown above, commissioning is assigned to warehouse management.[17]

Outgoing Goods:

The outgoing goods is the last interface in the company that processes the shipping of goods based on delivery requests. Articles are provided from the warehouse and the identity-/quality control, the creation of the accompanying documents, the systemic booking and the loading of the goods are ensured. Errors in this process step by the wrong identification of the goods can cause significant additional costs for the contractor as well as for the customer.[18]

1.7.2 Labelling

The VDA (Verband der Automobilindustrie) recommendation is a guideline for the labelling of packages (shipping units and individual packages) in the delivery processes of the automotive industry which optimally takes into account today's logistics concepts. The labels described (goods tags) enable a clear and continuous recording and tracking of the packages in the systems of all partners involved, including the transport service providers and support efficient incoming goods processes.[19]

---

[16] Vgl. specification sheet; provided by Jerich project management
[17] Vgl. specification sheet; provided by Jerich project management
[18] Vgl. specification sheet; provided by Jerich project management
[19] https://www.vda.de, viewed on 04.08.2018

Figure 12: VDA label

Figure 12[20] shows a standardized VDA label as used by Jerich International. The handling unit number is highlighted in red because the corresponding barcode contains all important information for warehouse management. Information contained:

- Supplier and customer information
- Delivery note number
- Part number, quantity and weight of the contents
- Routing information
- Data at the discretion of the supplier or customer

[20] source: https://www.vda.de, viewed on 04.08.2018, edited by the author of this thesis

1.7.3 Sources of Error

The VDA label is attached to the transport containers using adhesive dots. Depending on the customer or the type of container, the marking must be placed at specific points to avoid any malfunction in the customer's automated systems. A container must always be marked with a VDA label as it passes through the supply chain. If the label is missing or illegible, the bin and its content must be sorted out until it is clearly identified. The following reasons can cause a container to be blocked:

- Illegible label (e.g. due to soiling or damage)
- Label is missing
- Information of the label differs from the contents of the container
- Container or content are damaged (regardless of the VDA label)

A missing or heavily soiled label can be described as an obvious error and therefore easily recognisable. The worst case for this scenario is if a label is lost during the loading process on the trucks. The customer receives an unmarked container and complains about it, whereby Jerich International must bear the costs of reclamation. Therefore, the employees in the warehouse pay attention on the one hand to clean adhesive surfaces and on the other hand to the avoidance of bulges in the label, so that it is not stripped off when manoeuvring in confined spaces. Damaged goods or transport containers are already sorted out at goods receipt. As soon as the cause investigation and the determination of the severity of the damage has been completed, the further procedure is clarified with the customer. Even inside the warehouse, the forklift trucks can cause damage during transport. The most frequent cause of damage here is the falling over of stacked containers in the warehouse, due to excessive braking in the loaded state or lack of concentration during storage or retrieval in the narrow storage rows. Every accident or nearby accident must be reported to the shift supervisor or warehouse management.

The most difficult error to detect is a discrepancy between the information on the label and the actual content of the bins. To counteract this source of error, Jerich International has adapted a 100% check. This means, that every container that passes through the company's value chain, is inspected for conformity of label information with the container content. If a deviation is detected when the customer receives the goods, all consequential costs, such as reclamation costs, special trips or a decreasing supplier rating[21], are to be covered by Jerich. If there are several complaints within a short time, a temporary 200% inspection requested by the customer can be the consequence. A 200% inspection means that the entire inspection process must be performed twice. Also, the second inspection must be executed by a different employee than the first inspection. Striving for the highest possible customer satisfaction, the inspection process should avoid the additional costs mentioned. However, due to human error, 100% inspection does not result in 100% delivery quality.

[21] A low supplier rating, which is collected from the respective customers, can lead to the exclusion of participation in tenders of these customers. Another consequence may be quality audits.

1.7.4 Inspection Process Sequence

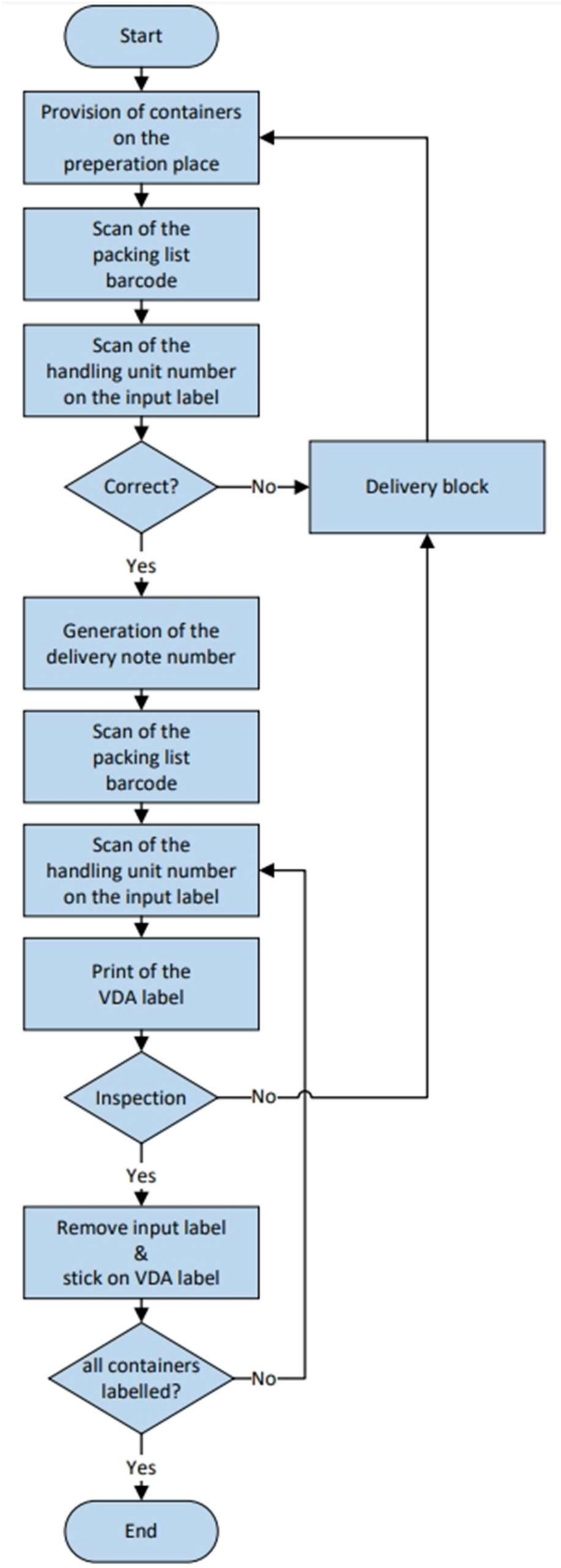
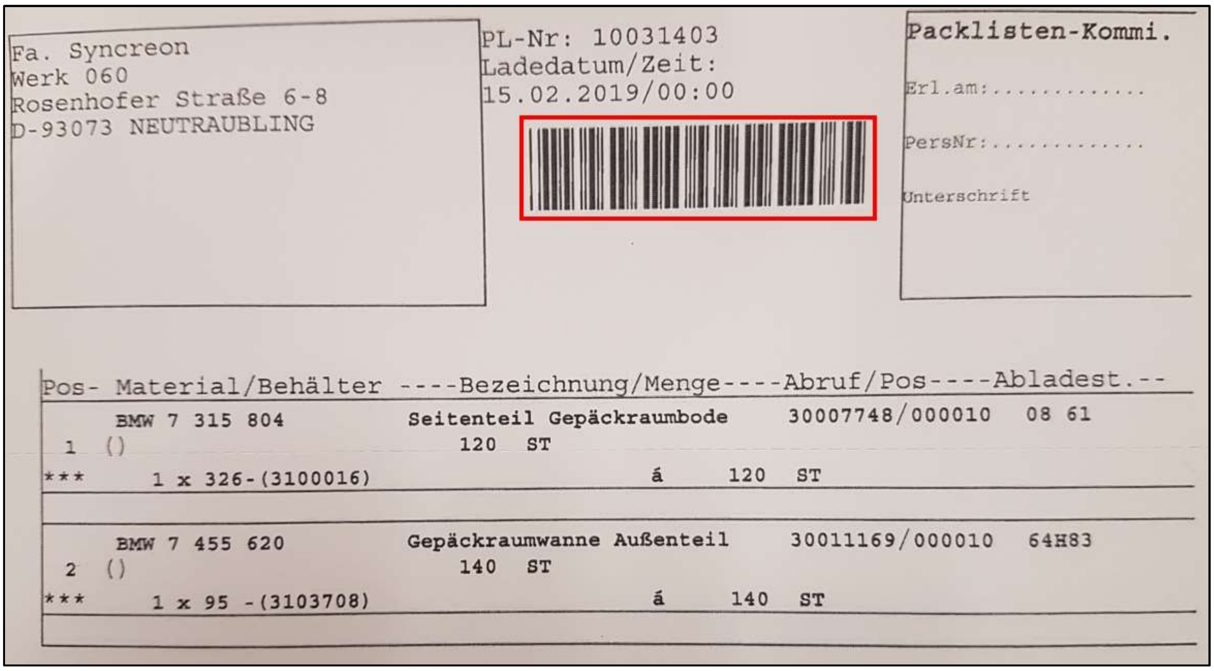


Figure 13: Actual inspection process[22]

[22] provided by Jerich project management; edited by the author

Figure 13 ***Fehler! Verweisquelle konnte nicht gefunden werden.*** shows the actual inspection process, which is calculated - in the warehouse management - with approximately 45 seconds per container (exclusive the transport time from the stock to the preparation place). This value also corresponds to the result of the time study in *chapter 3.1.7*.

In the first step, the goods are searched in the warehouse by using the packing list (pictured in *Figure 14*) and are then placed on the preparation areas (see *Figure 6).*


Fa. Syncreon
Werk 060
Rosenhofer Straße 6-8
D-93073 NEUTRAUBLING

PL-Nr: 10031403
Ladedatum/Zeit:
15.02.2019/00:00

Packlisten-Kommi.
Erl.am:.............
PersNr:.............
Unterschrift

Pos- Material/Behälter ----Bezeichnung/Menge----Abruf/Pos----Abladest.--
BMW 7 315 804 Seitenteil Gepäckraumbode 30007748/000010 08 61
1 () 120 ST
*** 1 x 326-(3100016) á 120 ST

BMW 7 455 620 Gepäckraumwanne Außenteil 30011169/000010 64H83
2 () 140 ST
*** 1 x 95 -(3103708) á 140 ST

Figure 14: Packing list[23]

Then the forklift driver scans the barcode on the packing list with a handheld and a stock transfer program. This procedure ensures that the containers, scanned in the next step, are posted to storage location code 250 (prepared for relocation) in SAP.

The handling unit number of each container is then scanned from the input label[24]. As soon as all handling units have been scanned, the employee checks in SAP whether all containers have been scanned correctly by entering the packing list number. If the delivery is complete in terms of quantity, the process can be continued by generating the delivery note number. If the compilation of goods is not complete, the entire delivery must be blocked until the missing containers are available. After the containers are available in the correct quantity and a delivery note number has been assigned, quality control in the narrower sense begins. This is because not only the number of containers, but also their content must correspond to all documents.

[23] provided by Jerich project management

[24] The input label is also a VDA label. The naming should support the differentiation between the input and the output label (called VDA label)

To create a VDA label, the delivery program is called using the handheld and afterwards the packing list barcode is scanned again. Next, the handling unit of the input label is scanned. The delivery program asks if the VDA label should be printed. After the employee confirms the request, the VDA label is then printed on a mobile printer. For this step, the input label is removed from the container. Once the VDA label is printed, the handheld expects the forklift driver to first scan the handling unit from the VDA label (external number) and then the input label (internal number). The forklift driver also checks that the part number on the VDA label matches the embossing of a physical part in the container. Each part has its part number stamped on it. In rare cases, a QR-Code[25] is etched instead, which also contains the specific part number by scanning with the handheld device. *Figure 15* shows an example of a QR-Code containing the Uniform Resource Locator[26] (URL) of the English Wikipedia mobile main page. If everything is correct, the VDA label is attached to the container using four adhesive dots.

Figure 15: QR-Code[27]

Afterwards, the input label of the next container can be scanned. This process loop is executed until all the containers in the delivery have received a VDA label. The outbound delivery documents can only be printed when the packing list is complete. Since a good overview of the inspection process is given, the link to the sources of error (presented in *chapter 1.6.4.1)* can be pointed out here. The inspection process is a routine task for every forklift driver in warehouse Gate 12. As described in more detail in *chapter 3*, an employee checks up to 279 containers per shift[28] on average, which may result in human error during inspection. Especially if a delivery contains left/right symmetrical components - the part numbers, which are usually very similar – the risk of not recognizing a deviation in the information increases. Another reason for incorrect labels is non-compliance within the work instructions, especially when employees are under time pressure. Although it is prohibited, some employees try to save time by first scanning all input labels and simultaneously matching the part numbers, then printing and stacking all VDA labels and then labelling in the same order. While this can save some time, an error in the order results in a fatal labelling error.

All these aspects are considered in the development of the prototype in order to eliminate the described error causes.

[25] QR-Code (Quick Response) is a two-dimensional matrix barcode
[26] URL (Uniform Resource Locator) is colloquially referred to as web address
[27] source: https://en.wikipedia.org/wiki/QR_code#, viewed on 08.01.2019
[28] a regular shift lasts 8 hours

1.8 Overview of the test bench prototype

As already explained in *chapter 1.2*, the elaboration of this master thesis takes place parallel to the development of the supporting technical solution – the prototype of the test bench for optical part identification. For this reason, it is not yet possible to show a final presentation of the newly planned work area here, but an overview can be given that is sufficient for the consideration of the processes. First the constructive design of the test bench prototype is introduced, then a short description of the developed image processing software as well as the data interfaces between the companies involved in the project is given. In the following the target process for the inspection is presented as well as the resulting advantages and disadvantages of the redesign.

1.8.1 Constructive Design

In addition to the technical and process related requirements, the new workspace must also meet industry ergonomic and safety standards. The objectives of the project, which must be fulfilled by the ivii project team, are listed in the specification sheet[29] and are presented in extracts as follows:

MUST-Goals:

The technical solution must…

- …support the employee in the identification of the part.
- …be able to uniquely identify the parts of the defined part scope.
- …give the employee a unique feedback on the status of the part identification.
- …increase delivery quality.
- …be integrable into ERP[30] and IT[31] systems via interfaces and enable data exchange between both sides.
- …be applicable and adaptable based on ergonomic industry standards.
- …be able to be integrated into the outgoing goods process and support the specified process throughput time.
- …support the process by optimizing the deployment of personnel.
- …include a test plan for manual identification of the part if system-supported identification of the part - by the technical solution - is not possible.

NOT-Goals:

- The technical solution must not be a prerequisite for meeting the quality requirements of the process.

[29] provided by Jerich project management
[30] Enterprise-Resource-Planning
[31] Information Technology

To avoid waiting times between the individual inspection cycles, it is necessary to ensure the timely feeding of the next container at the test bench. For this purpose, a conveyor system is provided next to the test bench. Offers for such a conveyor system are available and can be accounted in the economic analysis of the project.

Figure 16 shows a schematic representation of the work area. The workspace is inside the warehouse Gate 12 and can be assigned to the test bench area in the layout (*Figure 6*).

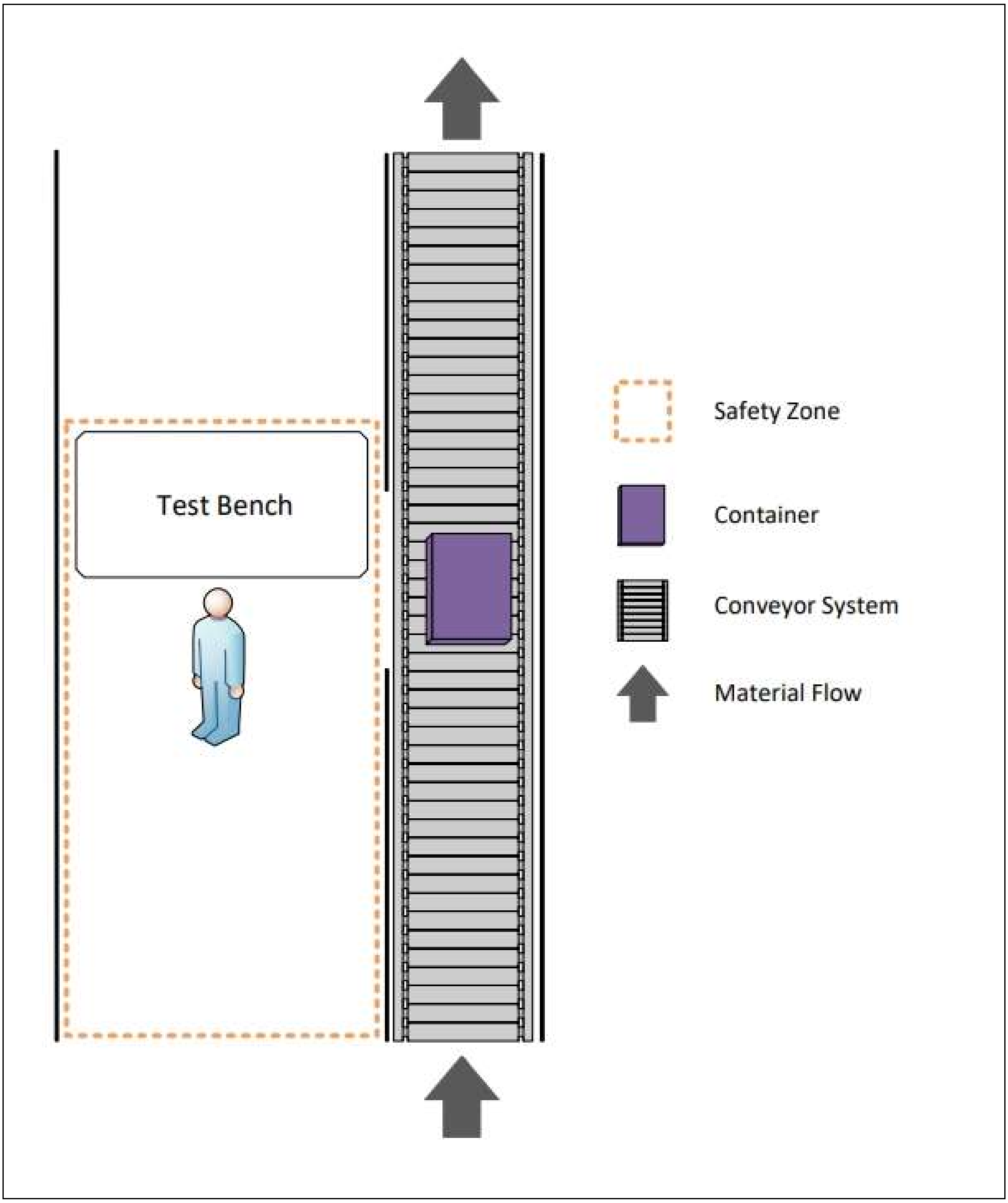


Figure 16: Schematic overview of the test bench area

1.8.1.1 Test Bench Prototype

During the development phase, a provisional test bench was set up to test the hardware and software. The test setup is shown in *Figure 17*. Core of the system is a 2D[32] camera and a transmitted light plate on which the parts to be inspected are positioned. Since the positioning of the components plays a role for a positive inspection result, the correct positioning is visualized on the touchscreen after the scan of the input label. The inspection can then be started with a push-button and the test result is clearly displayed on the touchscreen. In the final version of the test bench , the printing of the VDA label can be started if the inspection result is positive.

Figure 17: Provisional test setup

To get an idea of the final version of the prototype, in *Figure 18* and *Figure 19* screenshots of the design drawings are included. They are property of ivii and cannot be made available in a higher quality or in English.

[32] 2D is a common abbreviation for two dimensional

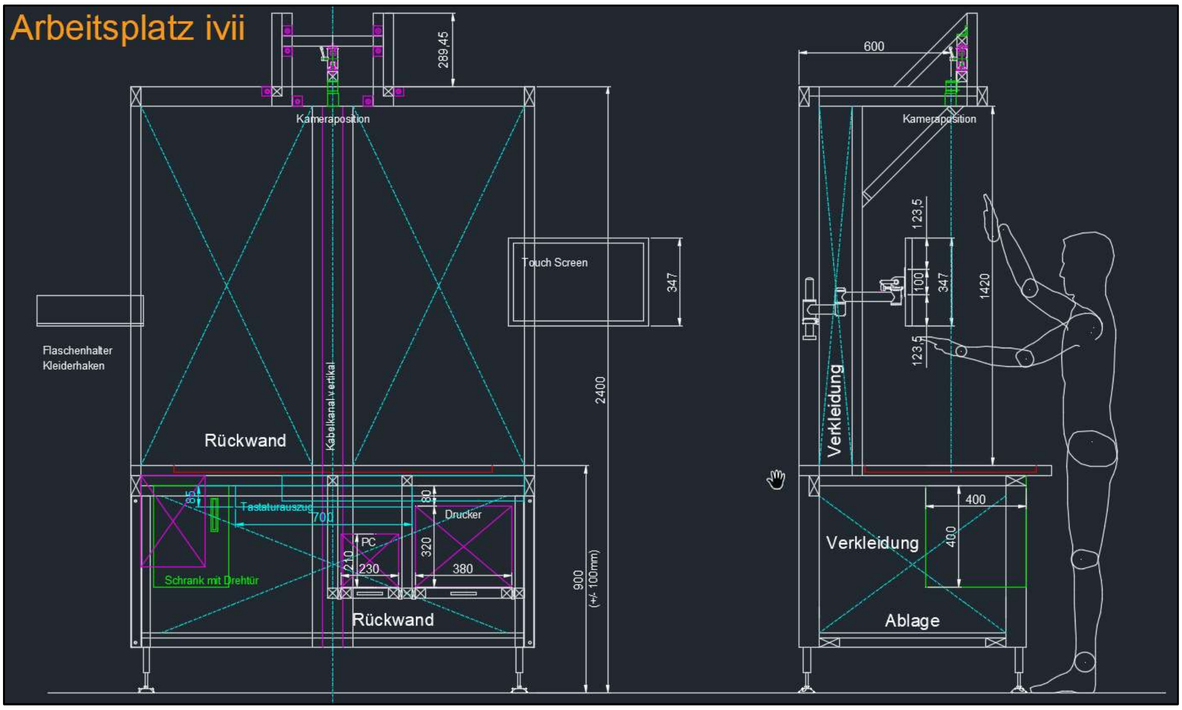


Figure 18: Front & side view of the test bench[33]

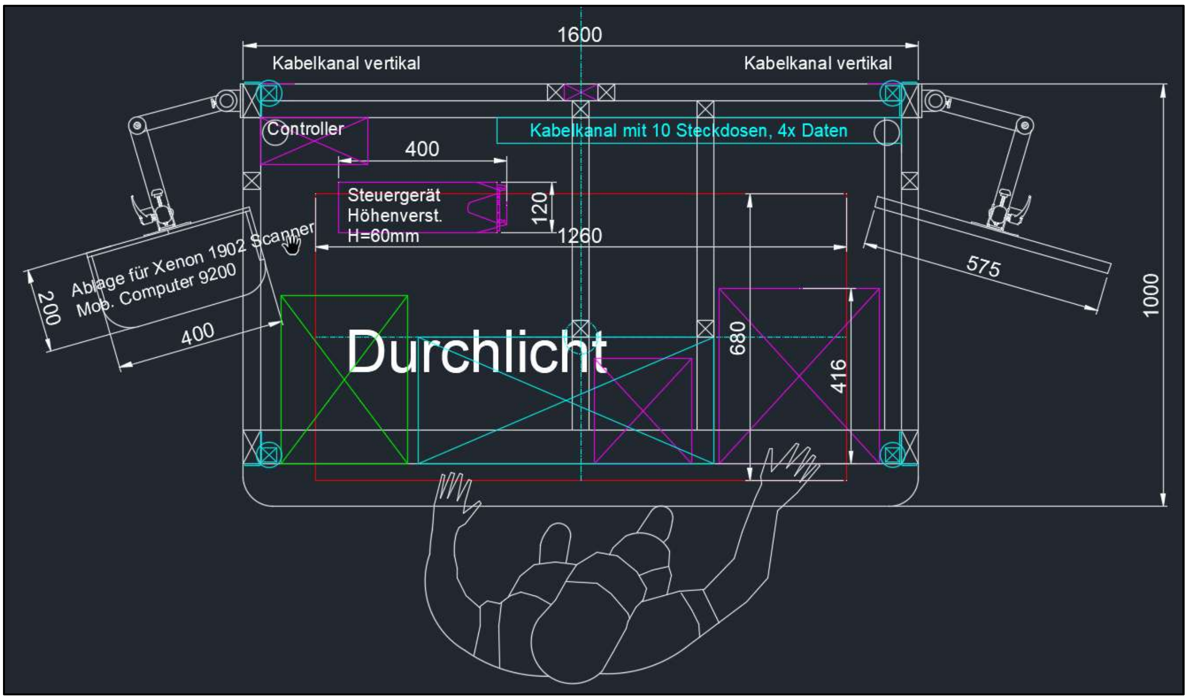


Figure 19: Top view of the test bench[34]

[33] source: provided by ivii project management
[34] source: provided by ivii project management

1.8.1.2 Conveyor System

The reason for a conveyor system is the time-efficient feed and discharge of the transport containers at the test bench. The conveyor system creates a buffer between the forklift transport and the test bench. The calculation of the transport times for forklift trucks in *chapter 3.1.8*, confirms the necessity for such an equipment. In addition to the basic transport function, a stacking and unstacking of up to three containers is also to be realised. The concept of the conveyor system can be seen in *Figure 20*.

Figure 20: Concept of the conveyor system[35]

1.8.2 Image Processing Software

The images generated by the 2D camera are analysed by an image processing program developed by ivii. Before a part can be inspected on the test bench, it must be created in the database of the software. For this purpose, the component is positioned on the transmitted light plate and photographed as in the later regular test mode, whereby a subprogram is used for teach-in. The image processing program then defines the distinctive features of the component and saves them. If an already taught-in component is tested, it is photographed again during the inspection process and the image is compared with the database. Because the input label is scanned before the inspection, the system already knows which components should be in the container. If all characteristics are identical, it is the same component and the inspection ends with a positive result.

[35] source: provided by Jerich project management

Due to the transmitted light plate there are high contrast differences in the images. The following features are particularly important for unambiguous identification:

- Surface of the component
- Contour of the component
- Position and size of potential drill holes

1.8.3 Data Interfaces

The data interfaces are shown graphically in *Figure 21*.

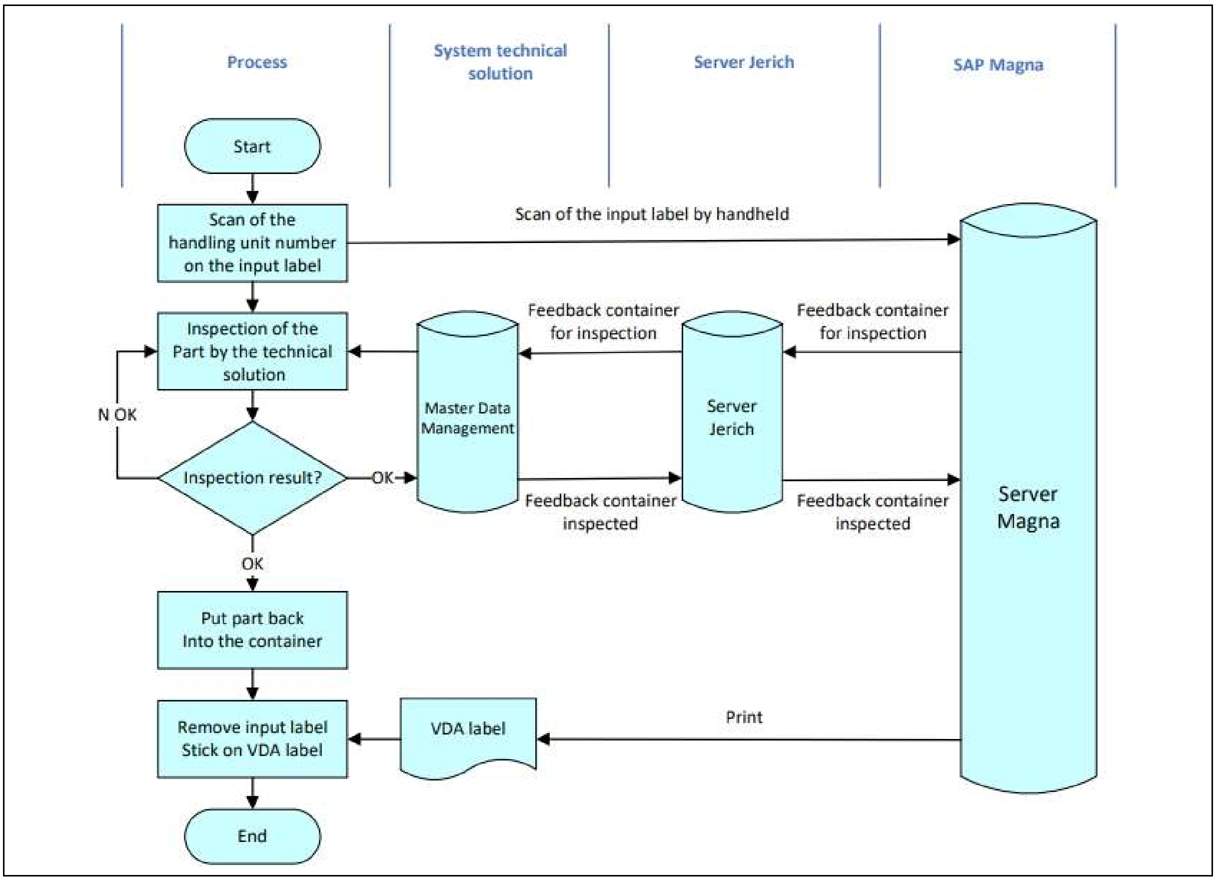


Figure 21: Data Interfaces[36]

If the input label is scanned using the handheld, the component data is queried from the SAP Magna. This feedback is sent to the Jerich server, which in turns sends the data to the master data management of the technical solution. The test bench communicates the positive inspection result back to the Jerich server and from there to Magna's SAP. Only now, the VDA label can be printed on the test bench.

[36] provided by Jerich project management; edited by the author

1.8.4 Target Inspection Process

The new inspection process (depicted in *Figure 22*) should start mentally after the supply of a new container by the conveyor system. The first step is to scan the input label with the handheld. As described in the previous chapter, the master data management of the test bench now queries all information of the part from the customer server.

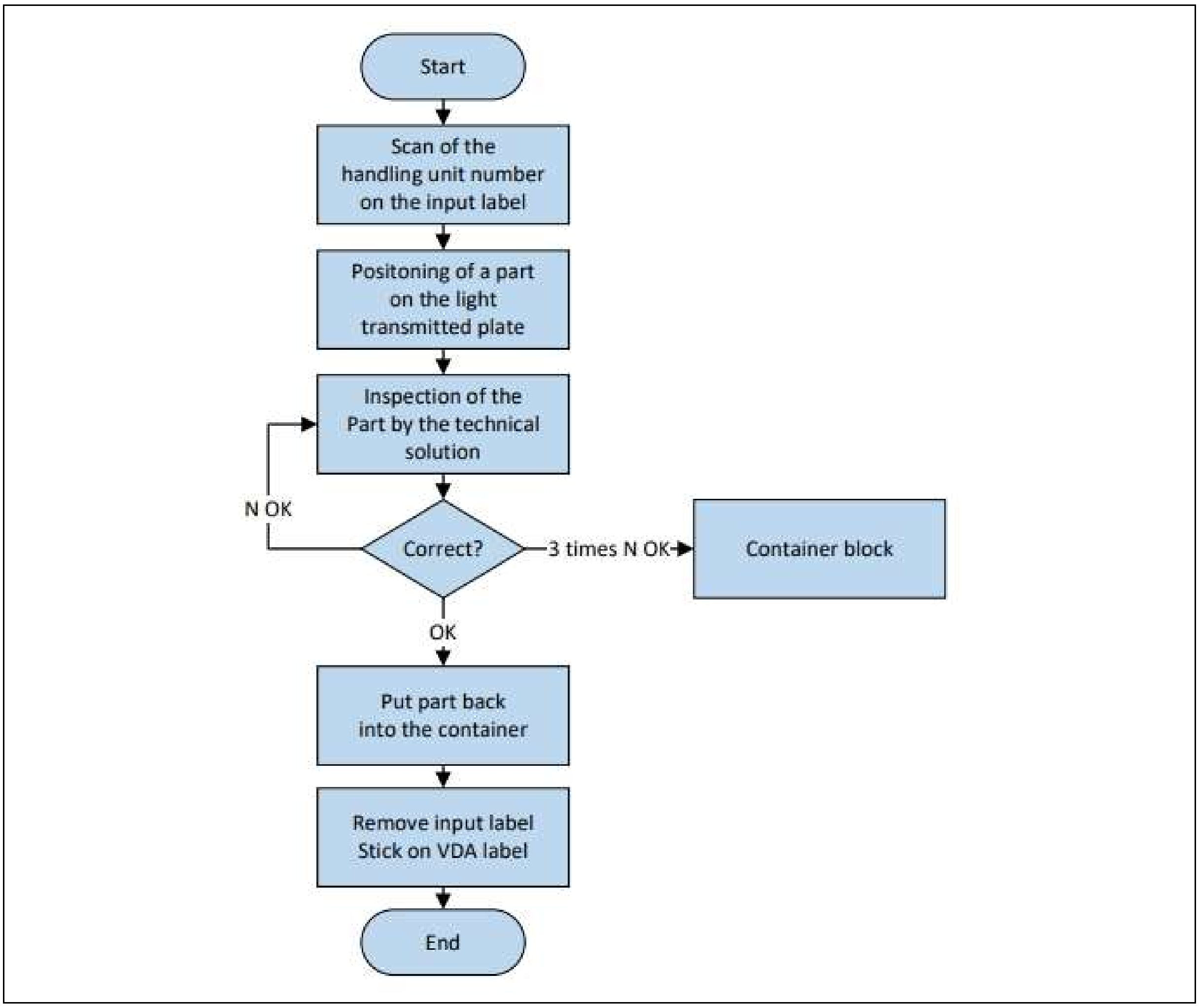


Figure 22: Target inspection process[37]

Meanwhile, the employee takes a random part out of the transport container and positions it on the transmitted light plate. On the touchscreen all relevant data of the component is shown to the employee, as well as a recording of the teach-in procedure. As soon as the employee has positioned the part properly, the inspection can be started with the bumper.

Left/right symmetrical components are particularly problematic. It happens that the left part is made from exactly the same tool as the right part. It can also be a small assembly, such as an articulated girder, which can be made of exactly the same parts for both left and right. In these cases, the features inspected by the image processing software are logically identical between

[37] provided by Jerich project management; edited by the author

the left and right components. Fortunately, such identical components or assemblies are difficult - for all participants in the value chain - to distinguish. For this reason, such products are already provided with a QR-Code by the manufacturer. Instead of comparing the optical characteristics (which would not lead to an unambiguous result), the QR-Code is scanned instead.

After a few moments, the inspection result appears on the monitor. This is clearly positively or negatively supported by green or red colouring. If the test result is negative, the inspection can be repeated 2 more times in order to be able to readjust if the positioning is inaccurate. The transport container concerned is marked as blocked and sorted out for further clarification, if the result remains negative. Is everything correct (all characteristics are marked green and the result is positive) the process continues with the next step.

The employee at the test bench sorts the inspected part back into the container and the new VDA label is printed at the local printer. The input label is then removed from the bin and the new label is attached. The target inspection process is now complete.

At the time of completion of this master thesis, it has not yet been finally clarified whether the conveyor system will have a separate control option, or if the bumper of the test bench will be used to control this system. Therefore, in this process representation, the transport of the inspected container and the request for the next untested container - by means of the conveyor system - are missing.

1.9 Comparison of the Inspection Processes

As the last chapter of the introduction, the actual and the target inspection process are compared in order to summarize commonalities and differences.

For the economic analysis of the entire project, the process duration and the quality improvement are of major interest. Both processes can be carried out within 45 seconds, so that neither an improvement nor a deterioration occurs.

With regard to quality improvement, no verified statement can be made currently. Only if the test bench and the new processes have been implemented in the regular day-to-day business, measurable statements about delivery quality can be made. For this reason, it is assumed in the further course of this thesis, that the desired error-free delivery performance will be achieved. Approximately 98%[38] on average is given here as the initial value for the delivery quality to emphasise the effort required for around 2%. Although there are no measurable results yet, at least the arguments for an increase in quality and a positive impact on other aspects can be summarised as follows:

- **Reduction of Human Error Sources:**
    - The employee no longer has to remember or compare part numbers
    - Deviations from the work instructions to save time or due to a lack of concentration are no longer possible due to the design of the workplace (protective grids prevent access to the next containers, operating range of the scanner is limited, software guides through the process)

- **Improving Ergonomics and Safety**
    - Adjustable table height
    - Optimally arranged peripherals
    - Clear HMI (Human-Machine Interface)
    - Away from forklift traffic
    - Away from the storage locations (no risk of being hit by falling containers)

- **Improvement of Traceability and Documentation**
    - User login at the test bench
    - Possibility of archiving the inspection images

[38] provided by Jerich project management

2 Theoretical Basics of this Thesis

In this chapter the theoretical basics of this thesis are presented. A common tool for solving such problems is the investment calculation, which represents a sub-area of business administration. As explained in more detail in *chapter 2.2* and *chapter 3.2*), the investment calculation usually uses some data which can only be determined exactly in the future due to the future orientation of the problem. Therefore, assumptions must be made to be able to determine these data sufficiently exactly. In the concrete case of the “optical part identification” project, the material flow analysis (to be assigned to the field of logistics) is used as a method to describe the changes in processes and their effects on costs (*chapter 2.1* and *chapter* 3.1). In summary, it can be said that the outcome of the material flow analysis represents a significant part of the input for investment cost accounting. Hence, the logistical basics are discussed first, followed by the investment calculation. In addition, an insight into the time study is given.

2.1 Logistic Basics

For a better understanding, specific terms of logistics are explained in this chapter, which are directly related to the project or the solution finding for the economic problem of this master thesis.

2.1.1 Aims of logistics

The economic goal of logistics is to improve material availability with the help of maximum return on investment. To achieve this, logistics shapes the relationships in economic systems (see *Figure 23*), in particular:[39]

- dispositive logistics: the part of the information flow between customer and supplier that is linked to the material flow (orders, delivery notes, delivery dates)
- physical logistics: material flow from subsystem supplier to subsystem customer

Just.in-Time (JIT) principle, which refers to the requirements of processes for which exact time specifications must be adhered to. JIT requests are defined by the customer, so this is the pull principle. The idea is to be able to react quickly to market needs. The "5Rs" result from the definition of just-in-time:[40]

- the **r**ight product or the **r**ight performance
- at the **r**ight time
- in the **r**ight quantity
- in the **r**ight quality
- in the **r**ight place.

[39] Vgl. KOETHER, R. (2018), S. 37
[40] Vgl. BERTAGNOLLI, F. (2018), S. 84

Sometimes the term "6R" is used, with the addition "at the right price". This means that the topic of costs to be reduced is also considered.[41]

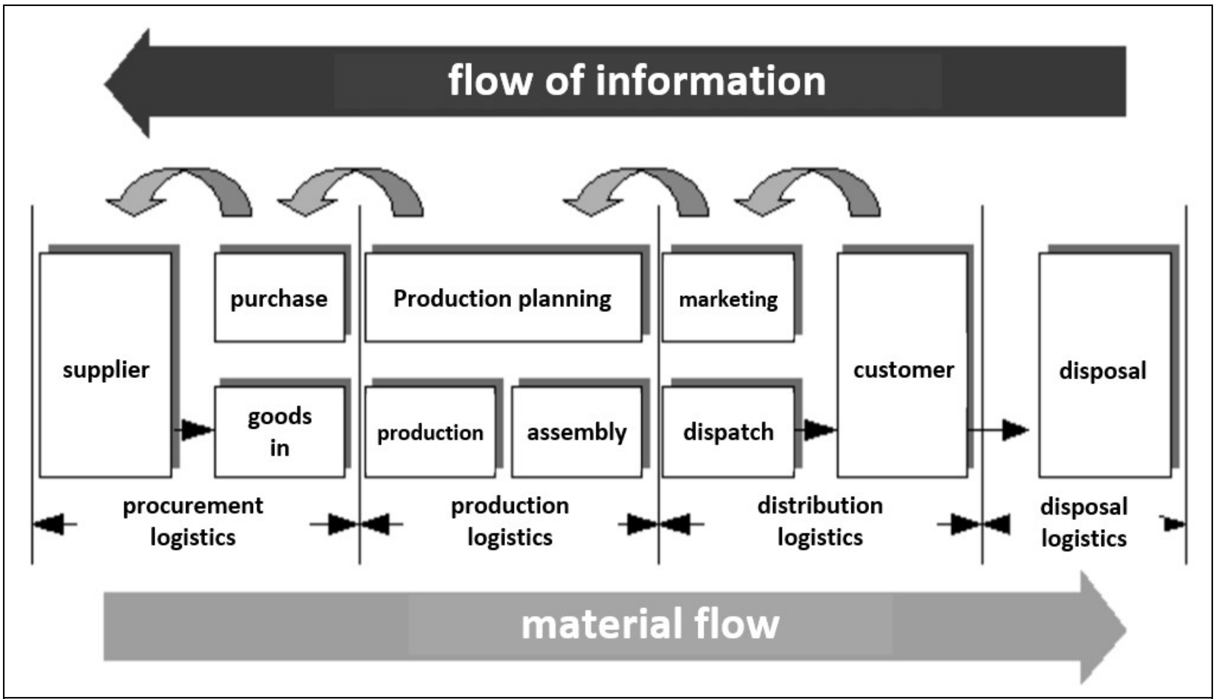


Figure 23: Logistics chain[42]

2.1.2 Chaotic Block Storage

In the row warehouse, there is a path between the warehouse goods so that the handling devices can directly access each storage compartment. In block storage, the stored goods are so close to each other or on top of each other that not every single container can be accessed directly. This makes very good use of the available space as can be seen in *Figure 24*. However, the access times to a certain stored good can be longer than with row storage if restacking becomes necessary. Block storage systems are suitable:[43]

- If the blocks are sorted by type, so that any container can be accessed
- For the storage of “low-runners”[44], for which restacking can also be accepted because of the rare access

[41] Vgl. BERTAGNOLLI, F. (2018), S. 84
[42] source: vgl. KOETHER, R. (2018), S. 37, edited by the author
[43] Vgl. KOETHER, R. (2018), S. 330 f.
[44] in contrast to "high-runners", "low-runners" are those goods that are rarely transhipped in relation to all goods in the warehouse

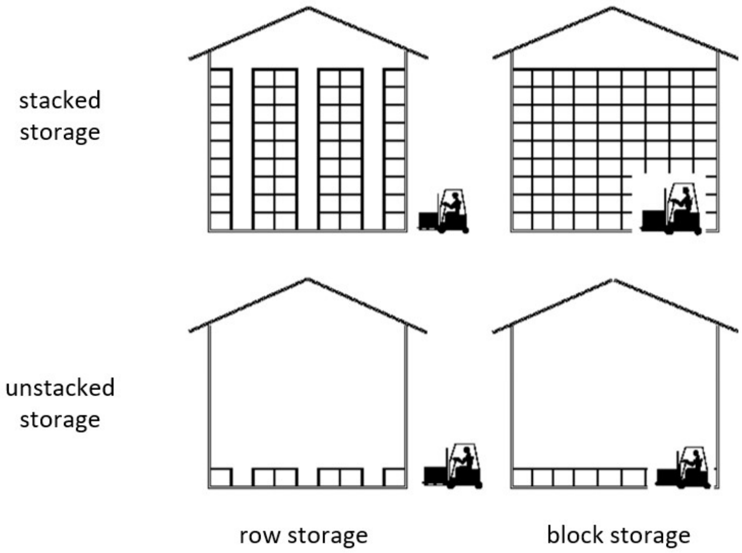


Figure 24: Block storage and row storage[45]

In addition to the arrangement of the storage bins, you can also differentiate how the goods are assigned to the individual locations. In *Table 1* the most common possibilities are listed.

Table 1: Storage location assignment[46]

Storage location assignment	**Characterisation**	**Advantages**
Fixed storage location assignment (systematic warehousing)	Articles are assigned to a fixed storage location	Access security in case of loss of the stock file; Separation of product groups
Lateral distribution	Storage units of an article are distributed over different rows	Access security in the event of failure of a shelf conveyor vehicle
Free storage location assignment (chaotic warehousing)	Storage units can be assigned to any shelves or storage locations	Storage capacity can be optimally used
Free allocation of storage locations within fixed areas	Storage units are stored within predefined areas	Separation of material groups; more capacity efficient than the fixed storage location assignment

In the case of chaotic warehousing the goods can be stored in any available storage location. Since no storage locations are reserved, the space requirements of different articles can be balanced by overstocking and understocking, so that fewer storage locations have to be installed overall. However, to find the stock items again, the storage locations must be carefully booked. This task is normally performed by the warehouse management computer.[47]

[45] source: vgl. KOETHER, R. (2018), S. 330, edited by the author
[46] source: vgl. MUCHNA, C.; BRANDENBURG, H.; FOTTNER, J.; GUTERMUTH, J. (2018), S. 89
[47] Vgl. KOETHER, R. (2018), S. 338

A further distinguishing feature between different storage types is the order in which goods are put into and removed from storage. In the case of warehouse Gate 12, the First In-First Out (FIFO) principle is used. This means that the goods that were first put into stock at a storage location, are first removed from stock again. The Last In-First Out (LIFO) method can be considered the opposite of the FIFO technique. The last good that was put into storage is also retrieved first. However, there are other methods which are not mentioned at this point, as they do not play a role in the project under study.

2.1.3 Commissioning and Sorting

Private and commercial consumers are supplied with goods from a wide variety of suppliers. The consumption quantities of each individual consumer are almost always smaller than the production quantities of each manufacturer. Part of the logistical connection between customers and supplier is commissioning, which represents the logistics function of retailing.
Every customer who buys in the supermarket and collects the goods in the shopping cart also performs a commissioning task. This logistics service is paid by the customer and therefore adds value. Since larger quantities are delivered to the warehouse or to the commissioning system, commissioning involves the removal of partial quantities from a larger storage or packaging unit. As the articles have different shapes, sizes and weights, automatic picking is only possible in exceptional cases. The human hand is still the most flexible "extraction tool".
Due to high wage costs, one of the main design goals of commissioning systems is to optimize the picker's productivity.[48]

2.1.4 Packaging

Packaging and containers are combined under the term conveying and storage aids. They are intended to simplify the transport and storage of goods. In addition, they should be as light, inexpensive, easy to handle and to dispose of as possible. Conveyor and storage aids are used for the following logistical reasons:[49]

- Facilitation of transport, handling and storage:
  - Holding the conveyed goods together
  - Savings on reloading operations
  - Standardization of the interface to warehouse and conveyor technology and facilitation of a mechanized or automated material flow
- Protection of the conveyed material against climatic influences, damage, contamination and theft
- Carrying product information, e.g. description of the goods, quantities
- Presentation of the brand image and advertising messages (especially for consumer goods)

[48] Vgl. KOETHER, R. (2018), S. 51 f.
[49] Vgl. KOETHER, R. (2018), S. 52 f.

2.2 Investment Calculation

The main objective of this master thesis is the economic consideration and evaluation of the project optical part identification. For this purpose, as a proven tool for problems of this kind, the investment calculation is used as one of the special fields of business administration. In this chapter, insights into the basics of investment calculation as well as into the calculation methods will be given.

2.2.1 Aim and Definition of the Investment Calculation

In principle, investments contribute to technical and social progress in the areas in which investments are made. For example, expansion investments in wind turbines in wind farms lead to a stronger supply of electricity from this sector, while the reduction in replacement investments in coal-fired power plants leads to a decrease in the supply of electricity from this sector. This results in a change that is presumably desired by society as a whole at the moment. The know-how created in connection with the financial investments in this area will help or improve the corresponding industry and society. Investment activity is therefore of great relevance. The term “investment” is not clearly defined even in business terminology. Depending on the author and the situation, it means different things. This is how the term is used:[50] [51]

- The cash expenditure for an investment object (a financial transaction)
- The procurement of a fixed asset (a transaction that forms fixed assets)
- The calculation of the advantageousness of an object

An investment should always create an improved situation compared to the initial situation. The probability of this happening increases with the use of investment calculation methods. The success of investments - for the future of enterprises - is particularly significant, since:[52] [53]

- Investments often tie up a high proportion of the capital
- Investments tend to lock up capital for a long time

Thus, the operational flexibility is strongly reduced by an investment. The capital tied-up can usually only be mobilized again at greater losses, before the planned useful life expires. The acquired investment often also determines the direction in which a company is active within relatively narrow limits, since the purchased asset can only be used for a few purposes. It is important that the investment decision is always made by the investor and never by the calculation procedure itself. The investment calculation procedures are always an academic

[50] Vgl. POGGENSEE, K. (2015), S. 6 ff.
[51] Vgl. GÖTZE, U. (2014), S. 3 ff.
[52] Vgl. POGGENSEE, K. (2015), S. 6 ff.
[53] Vgl. GÖTZE, U. (2014), S. 3 ff.

model – a simplified representation of reality – that cannot always represent all criteria for decision-making.[54] [55]

2.2.2 Phases of the Decision Process

The decision-making process for an investment can be divided into several phases. The actual investment calculation using an investment calculation method is only a small fraction of the overall decision-making process. The different phases of the decision procedure are listed below and briefly described:[56] [57] [58]

1. **Excitation Phase:** Here it is assumed that a company has clear corporate objectives derived from its corporate vision, corporate mission and corporate strategy. Strengths, weaknesses. Opportunities and risks are derived from these corporate goals. The emergence of new processes or cheaper machines may necessitate a replacement investment to maintain competitive strength. Similarly, information about the behaviour of the competition can make it important to take action accompanied by an investment. Conversely, information coming from the company itself about the necessity of expansion or rationalization or replacement of investment objects is recorded. If these suggestions are in line with the objectives of the company, the investment calculator enters the subsequent phase.

2. **Planning Phase:** The planning phase itself is divided into:

    - Definition of target criteria
    - Collection of possible alternatives
    - Concentration on the alternatives to be considered more closely
    - Calculation of the results of investment calculation methods
    - Coordination with other departments

    First of all, a concrete target is set for the planning problem, whereby it must be determined whether there are non-monetary as well as monetary criteria.
    Once the criteria have been defined, the most labour-intensive part of investment planning is usually the collection of data. First, all known alternatives are determined. From these alternatives, those that do not meet the exclusion criteria are eliminated. For the remaining alternatives, the planned data may have to be detailed, which is quite time-consuming. After the data collection for the possible alternatives, the investment calculation is done. Care must be taken to ensure that defined target criteria and the selected investment calculation method do not conflict with each other.

[54] Vgl. POGGENSEE, K. (2015), S. 6 ff.
[55] Vgl. GÖTZE, U. (2014), S. 3 ff.
[56] Vgl. GÖTZE, U. (2014), S. 14 f.
[57] Vgl. POGGENSEE, K. (2015), S. 22 ff.
[58] Vgl. SCHÖNBOHM, A.; ZAHN, A. (2012), S. 5ff.

In coordination with other departments of the company, the financing and capacity planning - not taken into account in the investment calculation itself - must be carried out. In financial planning, the origin of funds and the liquidity must be planned. In capacity planning, the entire supply chain for a new investment object may have to be adjusted. Space capacities, personnel capacities and bottlenecks in the production process need to be analysed and the sales of the products with the required organization and logistics need to be determined.

3. **Decision Phase:** In this phase the investor has to make the investment decision, because the investment calculation cannot make the investment decision itself due to its character as an academic model and the limited forecast quality of the planning data. The investment calculation itself only has the task of structuring the decision problem to the maximum possible extent and reducing the complexity of the decision process by determining an investment calculation key figure.

4. **Realisation Phase:** Here it is to be monitored that the planning is identically converted into reality. Any negative deviation from the plan data, such as higher construction disbursements for the construction of a system, can make the investment opportunity uneconomical.

5. **Control Phase:** The control has already regularly accompanied the other phases and closes the loop. Here, recalculations and deviation analyses are made.

2.2.3 Characterization of Investments

Investments in companies occur in a variety of different forms. *KERN* distinguishes between peripheral and central classification criterions.[59] [60]

Peripheral criteria:

- Investment object
- Investment occasion
- Investment area

Central criteria:

- Consequences of investments
  - for quantitative oriented consideration
  - for quality-oriented consideration
  - for temporary oriented consideration

[59] to the following statements vgl. KERN, W. (1974), S. 10 ff.
[60] to the following statements vgl. GÖTZE, U. (2014), S. 7 ff.

- Interdependence of investments
- Level of uncertainty

According to *GÖTZE*, a differentiation of investment types by peripheral classification criterions is suitable for concrete investment problems in companies. Therefore, the peripheral differentiation possibilities are discussed in more detail.

2.2.3.1 Investment Types by Object Criterion

As shown in *Figure 25*, the criteria of the investment object can be used to distinguish between financial investments and real investments.

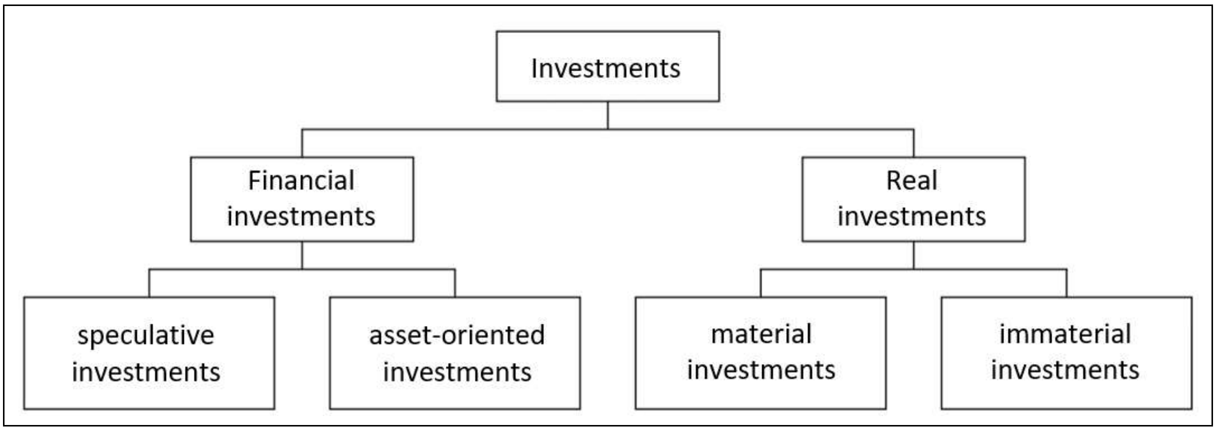


Figure 25: Investment types by object criterion[61]

Financial investments are capital tied up in financial forms of investment, such as deposits at banks, bonds, investment certificates, real estate fund units or participations. They have either speculative or investment-oriented character.

Real investments can be subdivided into material or goods-based investments and immaterial or potential investments. In case of potential investments, intangible goods are generated - for example through training and further education, advertising and research and development. These can be knowledge or employee potentials in the company as well as potentials of the company with external persons or institutions. Material investments, conversely, serve to provide physical resources, which include operating resources in particular, but which can also include renewable resources such as forests in a forestry farm. The production factor "operating resources " includes machines, land, buildings, vehicles and IT equipment. Finally, with regard to object-related investment types, it should be noted that products (or strategic business units) or the tools to manufacture and sell them can also be interpreted as investment objects.[62]

[61] source: GÖTZE, U. (2014) S. 8
[62] Vgl. GÖTZE, U. (2014) S. 8 f.

2.2.3.2 Investment Types by Occasion Criterion

A differentiation according to the criterion of the occasion for investment is possible especially for real economic investments. It leads to the distinction between construction investments, current investments and supplementary investments (depicted in *Figure 26*).

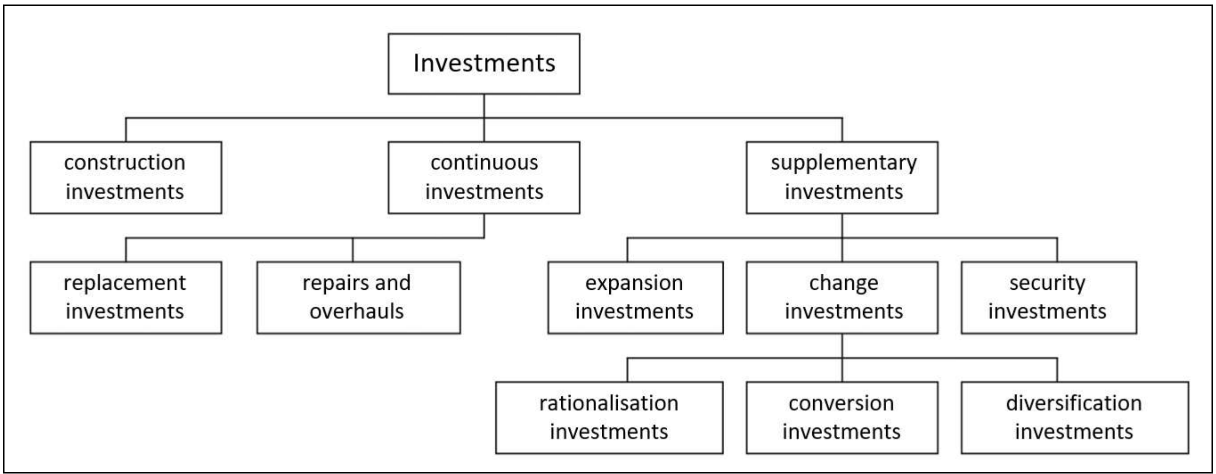


Figure 26: Investment types by occasion criterion[63]

With construction investments (initial investments, new investments, start-up investments) the activity of a company begins at a location. This may involve the founding of a new business of a company or the establishment of a subsidiary. Current investments include major repairs and overhauls on the one hand and replacement investments on the other. A pure replacement investment exists when operating resources are substituted by identical objects. Often a replacement is made by an improved operating resource. Replacement investments are then at the same time rationalisation and/or expansion investments. In general, a clear classification according to the occasion criterion can cause difficulties. Supplementary investments as well as current investments relate to operating resources at existing locations. Supplementary investments include expansion, change and protection investments. Expansion investments lead to an increase in the capacity or capability of a company. A characteristic feature of change investments is the modification of certain characteristics of the enterprise, which may have different motives. Rationalisation investments primarily serve to reduce costs, conversion investments to adapt to changed sales volumes of the previous product types and diversification investments to prepare for changes in the sales programme, which are caused by the introduction of new products or the supply of new markets. Differentiating between expansion and change investments is often problematic, since capacity expansion is usually accompanied by changes in company characteristics. Finally, protection investments are measures, which are suitable for eliminating or preparing for sources of danger for the company.[64]

[63] source: vgl. GÖTZE, U. (2014), S. 10, edited by the author
[64] Vgl. GÖTZE, U. (2014), S. 9 f.

2.2.3.3 Investment Types by Area Criterion

The third peripheral classification criterion is that of investment areas. This criterion subdivides the company by the functional areas in which an investment is made. Investments in the areas of procurement, production, sales, administration, personnel and research and development can therefore be differentiated. Classification according to the area criterion is also applicable to real economic investments.[65]

2.2.4 Development of the Investment Calculation

At this point, no historical review of the investment calculation should take place. Basically, the investment calculation is a rather static field of knowledge, in which in the past twenty to thirty years no decisive research findings could be achieved. This is because the mathematical models, that form the basis of investment calculation procedures, have theoretically been mature for a long time. The investment calculation strives for the most accurate possible representation of cash flows and uses incoming and outgoing payments[66]. The problem lies primarily in the procurement of reliable data. Since an economically oriented investment decision must always use forecast values of future economic success numbers, forecast models must be used to estimate these values[67]. However, since the future is still not exactly predictable in most cases, this is the real weakness of the realism of the calculation results. At a time when computers and pocket calculators were not widely used in companies, the use of static investment calculation methods was a useful tool for supporting company decisions. With the spread of pocket calculators, it was also possible to carry out dynamic investment calculation procedures in companies with a justifiable amount of work. In addition to the consideration of the time frame, the complexity of the decision problem has an influence on the investment calculation method used. A static investment calculation procedure is certainly justified for the evaluation of a purchase with an acquisition payment of 50 euros because of the low importance of this investment. The third relevant aspect for the use of the investment calculation methods - in addition to the existing IT and the importance of the investment object - is probably the company size. While the know-how about complex investment calculation procedures is certainly available in large corporations, this is not necessarily a matter of course for a sole proprietorship. Thus, due to a lack of know-how, significant investments are often made here with too trivial investment calculation methods or completely without them.[68]

[65] Vgl. GÖTZE, U. (2014), S. 10
[66] Vgl. GRIEMERT, S. (2010), S. 22
[67] Vgl. SCHÖNBOHM, A.; ZAHN, A. (2012), S. 1
[68] Vgl. POGGENSEE, K. (2015), S. 18 f.

2.2.5 Investment Calculation Methods

Many different investment calculation methods available can be organized systematically under various aspects. Generally, a distinction can be made:[69]

- Procedures with and without consideration of risk
- Qualitative and quantitative methods
- Methods with one-dimensional and multidimensional objective functions
- Procedure for evaluating individual investments or investment programmes

The possibility of grouping individual methods into methods groups depends on various aspects. For example, the following method groups can be summarized:[70]

- Static investment calculation methods[71]
  - Cost comparison method
  - Profit comparison method
  - Average return method
  - Static amortisation period
- Dynamic investment calculation methods
  - Net present value method
  - Annuity method
  - Internal rate of return method
  - Dynamic amortisation period
- Methods for taking risk into account
  - Risk analysis[72]

Since the net present value method and the dynamic amortisation time are dedicated objectives of this master thesis, they are considered in more detail.

2.2.5.1 Static Methods

A characteristic feature of static methods is that the financial effects of investments are considered on a one-period basis - with the exception of static amortisation. By using average values, the one-year period is used as representative of the total useful life of the investment project. Since the considerations are not based on the entire planning period, but only on an annual accounting period, it is necessary to use periodic performance measures.[73]

---

[69] Vgl. POGGENSEE, K. (2015), S. 15
[70] Vgl. POGGENSEE, K. (2015), S. 15
[71] Vgl. MÜLLER, D. (2019), S. 328
[72] Vgl. KRUSCHWITZ, L. (2014), S. 322
[73] Vgl. MÜLLER, D. (2019), S. 328

Smaller companies rely completely or mainly on the group of static methods when preparing their investment decisions. The decisive advantages of static investment procedures are from a practical point of view: [74]

- The calculations are simple and therefore easy to understand even for "investment non-experts"
- the amount of data required to "feed" the static calculations is low and thus
- no differentiation is made over time

Simple issues, such as decision problems with few influencing variables, short running times and low investment sums, require equally simple models. As the complexity of the decision situation increases, so does the complexity of the models that represent this situation.[75]

2.2.5.2 Dynamic Methods in General

In contrast to static methods, dynamic methods calculate interest for incoming and outgoing payments at the exact time. There are two types of interest calculation:[76]

- Compound interest: is used to calculate the future value of an asset that is currently the existing capital
- Discounting: determines the present value of future expenditure or income.

With dynamic methods, interest is calculated on the payments. The following financial terms are important:[77]

- Net Present Value (NPV) or present value:
  A single payment K_n or multiple payments e are discounted to the present value K_0.
- Future value:
  A single payment K_0 or multiple payments e are compounded with interest and compound interest.
- Annual value or annuity:
  The regular constant annual contributions are used to pay interest and repay a debt

2.2.5.3 Net Present Value Method

An investment causes cash inflows and outflows (cash flows) that occur at different points in time. For this purpose, the present values of the cash flows are calculated at different periods. The sum of all these NPVs is the net present value. The following relationship applies:[78] [79]

[74] Vgl. KESTEN, R. (2006), S. 8
[75] Vgl. MÜLLER, D (2019), S. 337
[76] Vgl. HERING, E. (2014), S. 13
[77] Vgl. HERING, E. (2014), S. 13
[78] Vgl. HERING, E. (2014), S. 15 f.
[79] Vgl. SCHÖNBOHM, A.; ZAHN, A. (2012), S. 8

$$K_0 = \frac{e_1 - a_1}{q} + \frac{e_2 - a_2}{q^2} + \frac{e_3 - a_3}{q^3} + \cdots + \frac{L}{q^n} - a_0 \quad (1)$$

$$K_0 = \sum_{i=0}^{n} (e_i - a_i) q^{-i} \quad (2)$$

This applies to the variables:

e: Revenue in years of useful economic life
q: Accumulation factor
a: Expenditure in years of useful economic life
a_0: Acquisition value
L: Liquidation proceeds

The formulas take into account the fact that the earlier revenue arrives, the more valuable it is. The later the expenditure is incurred, the less effective it is. It has to be said:[80]

- Expenditure includes the total operating expenditure for the investment. In addition to the acquisition and installation costs for the investment object, this also includes material costs and wages for maintenance and repairs.
- The expected sales proceeds are also taken into account in the revenues.
- The net present value decreases with rising interest rates and increases with falling interest rates.

Table 2 shows the implications of the NPV method for the investment decision.

Table 2: Net present value for the assessment of investments[81]

Net Present Value	**Statement**
positive $K_0 > 0$ Investment advantageous	Investment generates not only the cost of the total investment, including the interest on the capital, but also an income of investment profit
$K_0 = 0$	Investment generates just the cost of the total investment including the interest on capital
negative $K_0 < 0$ Investment unfavourable	Investment does not generate the cost of the total investment including the interest on capital. There is an investment loss

[80] Vgl. HERING, E. (2014), S. 15 f.
[81] source: vgl. HERING, E. (2014), S. 16

2.2.5.4 Dynamic Amortisation Period

The dynamic amortisation calculation is similar to the static amortisation calculation. Instead of the time values of the revenue surpluses, the present values of the revenue surpluses are entered in the calculation. The dynamic amortisation period corresponds to the period in which the capital employed is repaid via the income surpluses and bears interest at the calculatory interest rate. This is why the dynamic amortisation period is always longer than the static one. The dynamic amortisation calculation does not necessarily lead to the same results as the net present value method in terms of absolute and relative advantages. The dynamic amortisation period can be determined by gradually calculating the accumulated present values of the net payments for each period of useful economic life. This cumulative present value corresponds to the net present value depending on the useful economic life. As long as this value is negative, the amortisation period has not yet been reached. If the value is positive (zero) for the first time, the amortisation time is exceeded (reached). If the first non-negative value is not zero, the amortization time is in the period whose end is considered. Interpolation can be used to approximate the portion of the period that is still required for amortisation.[82] [83]

$$I_A = \sum_{t=0}^{T_{Adyn}} (e_t - a_t) * (1 + i_k)^{-t} \tag{3}$$

This applies to the variables:

e: Revenue in years of useful economic life
a: Expenditure in years of useful economic life
I_A: Acquisition value
i_k: Calculatory interest rate [% p.a.]
T_{Adyn}: Dynamic amortisation period

2.3 REFA Time Study

In the 1970s and 1980s, the REFA Association set approved standards with the REFA Methodology, which have accompanied and strongly influenced the industry in Germany and Europe to this day. The demand to sustainably increase productivity and thus competitiveness has not changed in recent years and has become even more urgent. Industrial Engineering is a field that deals comprehensively with these questions.[84]

[82] Vgl. GÖTZE, U. (2014), S. 114 ff.
[83] Vgl. POGGENSEE, K. (2015), S. 137 ff.
[84] Vgl. REFA (2015), Vorwort

The following statements are a summary of the REFA Time Study:[85]

Objective: Determination of target times by evaluating actual times for activities.

Results: realistic time data for:

- Work planning
- Calculation
- Capacity planning
- Payment structure

Method: 4 steps as follows:

Preparation: The local conditions such as space available and position for observation must be clarified. The purpose for which the data is to be used must be determined. It must be determined whether the data is to include cumulative or individual times. The number of necessary measurements, the timepiece to be used and the recording sheet must be determined. The task, method, method and working conditions must be described. The participants must be selected and adequately informed.

Implementation: Representative conditions must be ensured, for instance by taking measurements throughout the working day. The results must be recorded in the documentation (system description, reference quantities, influencing variables, time recording sheet).

Evaluation: The evaluation of the data takes place in the seven steps:

- Check time recording for correctness and completeness
- Calculate actual individual times
- Statistical evaluation
- Calculate target times
- Calculate standard time
- Document possible approaches for improvement measures
- Record the evaluation of the load and stress situation

Presentation and application of results: The results are presented to the internal client. After approval, they are made available to the user areas via the operational IT systems and used by them. It should be examined whether the data thus obtained can also be used for other work systems. The time of a possible verification has to be determined.

[85] Vgl. REFA (2015), S 187 ff.

3 Practical Solution

In this chapter the elaborations of the concrete tasks - defined in *chapter 1.4* - are presented. The main focus of the logistic solutions is the provision of important information, both for the optimal implementation of the prototype test bench and for the best possible assessment of the monetary effects. The economic solutions provide the necessary key figures to provide the investor and the project management team with well-founded decision-making support for further steps.

3.1 Logistic Solutions

First, a quantity structure is created by analysing the warehouse data, which serves as the basis for further calculations. Subsequently, a layout is developed which meets the future requirements and serves as a basis for the calculations of the target situation. Then a comparison of the actual situation and the target situation is made to derive monetary statements.

3.1.1 “NOT-Kommi” Process

This process represents the focal point of the analyses, since the components that go through this process - as part of the optical part identification project - must be clearly identifiable by the test bench. Also, at the beginning of the implementation of the technical solution in the day-to-day business, only those containers that are assigned to the "NOT-Kommi" process will pass through the new inspection process.

As can be deduced from the designation, the components in their corresponding transport containers do not have to be commissioned. This means that the transport container leaves the warehouse with the same contents as at goods receipt.
The "NOT-Kommi" process is currently carried out during the night shift (22:00 - 06:00), as there is generally less activity in the warehouse at night and therefore more usable space is available for the employees. The lower forklift traffic is also an advantage. Depending on the transport volume, either 1 or 2 employees are deployed per night shift for this task.

For the investigations in this master thesis, the considered "NOT-Kommi" process is almost identical with the process representation in *Figure 13* in *chapter 1.7.4*. a holistic view of the process only misses the incoming goods including storage and the final loading in the outgoing goods. However, these process steps are not taken into account here because they usually take place during the day and are not affected by any changes.

A graphical representation of the site of the process - in warehouse Gate 12 - is shown in *Figure 33* in *chapter 3.1.9*.

3.1.2 “Kommi” Process

During the development of the prototype, the "Kommi" process plays only a minor role, as it does not require consideration for successful project completion. However, as already mentioned in the introduction, the project should be expanded if successful. Then this process will also run on the test bench and other sites will be equipped with the new technology.

In principle, the only difference to the "NOT-Kommi" process is that the goods do not remain unchanged in their transport containers. Depending on customer requirements, the components are picked in the desired quantity and in the desired containers. In most cases, the components are transferred from a larger source container into smaller boxes - so-called Kleinladungsträger (KLT) - and then packaged.

Nevertheless, this difference leads to problems concerning quality assurance. Commissioning is a very busy area and should be largely spared from additional tasks. There is also the problem of packaging. Currently, the forklift driver who transports the source containers from the storage location to the commissioning area is responsible for part identification. In contrast to the "NOT-Kommi" process, no VDA label can yet be attached as the goods leave the source container in the warehouse during picking. The VDA label is affixed by the commissioner to the finished packaged containers. In order to avoid quality problems, only homogeneous goods (identical part number) are allowed to be processed per commissioning area at the same time. An inspection after commissioning also proves to be inappropriate because the packaging would have to be destroyed in order to remove a component.

The only sensible approach - without loading the commissioning staff with additional tasks - is therefore to continue to inspect the source containers before commissioning. "Kommi" containers will also not receive a VDA label on the test bench. Instead, an internal marking is to be introduced which declares the container as inspected after successful part identification. A graphical representation of the site of the process - in warehouse Gate 12 - is shown in *Figure 33* in *chapter 3.1.9*.

Furthermore, from the forklift driver's point of view, considerably more different trips can be distinguished compared to the "NOT-Kommi" process. The following trips can be distinguished for the "Kommi" process:

- Storage place to commissioning (represents the actual process)
- Storage place to commissioning (represents the target process)
    - Storage location to test bench sink
    - Test bench sink to test bench source
    - Test bench source to commissioning
- Source container (not empty) from commissioning to storage location
- Empty containers from commissioning to empty containers area (see *Figure 6*)
- Storage location to storage location (average is used for calculation)

As can be seen from the calculation of transport distances in *chapter 3.1.6* and the determination of process times in *chapter 3.1.7*, future changes only affect the route from the storage location to commissioning.
This process takes place during the two day-shifts (06:00 - 14:00 ; 14:00 - 22:00).

3.1.3 Quantity Structure

For the entire planning of the project it is necessary to know the boundary conditions as precisely as possible. In order to determine these, it is necessary to make assumptions and restrictions in order to obtain a realistic picture of the situation. A model will be developed which reflects the current and target situation as realistically as possible. Therefore, an average working shift is determined.

In the first step, the question arises of how many containers per shift must be inspected on the test bench. For this task, SAP data[86] will be analysed from the beginning of January 2018 to the end of August 2018. This period was selected together with the warehouse management. On the one hand long enough to be able to calculate a representative average for the calculations, on the other hand short enough to avoid too large fluctuations in the assortment. Two data sets are analysed:

- Data for the “NOT-Kommi” process
- Data for the “Kommi” process

Since the raw data provided consists of approximately 34.000 lines in Excel, they are not shown here in their entirety. *Table 3* shows an excerpt of the raw data. At this point referred to as raw data because these were exported from the SAP database to Excel without modification. The following entries are particularly important for the calculations in this master thesis:

- Part number (“Material”)
- Booking date (“Buchungsdatum”)
- Quantity (“Menge in ErfassME”)

Table 3: Excerpt SAP data

Material	Materialkurztext	Buchungsdatum	Menge in ErfassME	Referenz
BMW 6 860 841.04 X	ZB Schubfeld mit Querstrebe MOL	02.01.2018	-58	0080751448
BMW 6 860 841.04 X	ZB Schubfeld mit Querstrebe MOL	02.01.2018	-116	0080751358
BMW 6 860 841.04 X	ZB Schubfeld mit Querstrebe MOL	03.01.2018	-116	0080751673
BMW 6 860 841.04 X	ZB Schubfeld mit Querstrebe MOL	04.01.2018	-58	0080751950
BMW 6 860 841.04 X	ZB Schubfeld mit Querstrebe MOL	04.01.2018	-116	0080751926
BMW 6 860 841.04 X	ZB Schubfeld mit Querstrebe MOL	05.01.2018	-58	0080752260

[86] provided by Jerich project management. The data are exclusively containers from BMW which were handled in the warehouse Gate 12

The procedure for the analysis of the data sets is almost identical for both. The raw data for the "Kommi" process contain entries, also on weekends and some public holidays. Nevertheless, since these are considerably less extensive than those on normal working days, they are not taken into account to not falsify the average downwards. However, some goods were only recorded on weekends. To ensure that these part numbers are not missing in the quantity structure, all data is used for further calculations (including weekends or public holidays), but then adjusted by a linear error correction. The error that occurs in this way is 12.48%[87]. This means that in the calculations of the "Kommi" process the calculated transport volume must be corrected downwards by this value in order to correspond to the determined container average per shift.

Figure 27 and *Figure 28* show the transport volume of containers from January 2018 to August 2018 for the respective areas under investigation. At this point it should be mentioned that the data of the "Kommi" process always contains two shifts per working day. For this reason, all calculated values for this process must be halved at the end to obtain the numbers for one shift.

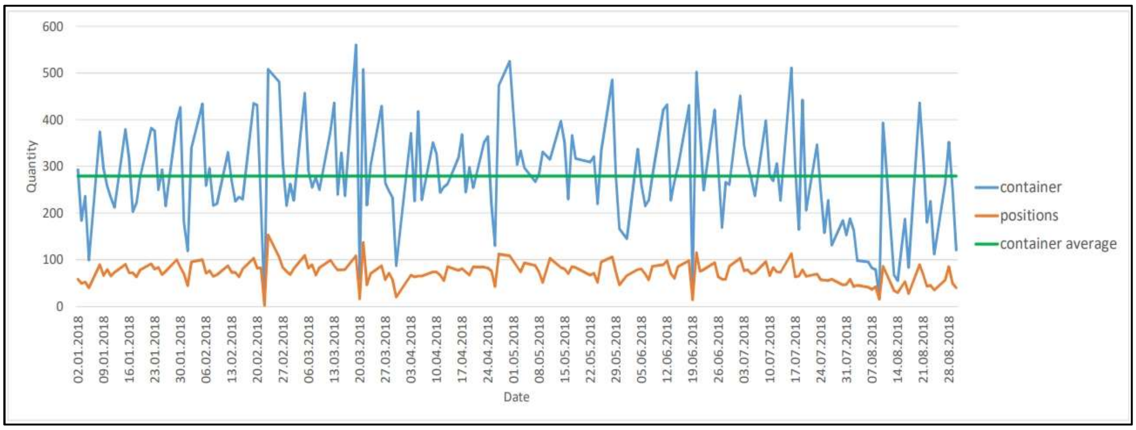


Figure 27: "NOT-Kommi" container transport volume January 2018 - August 2018

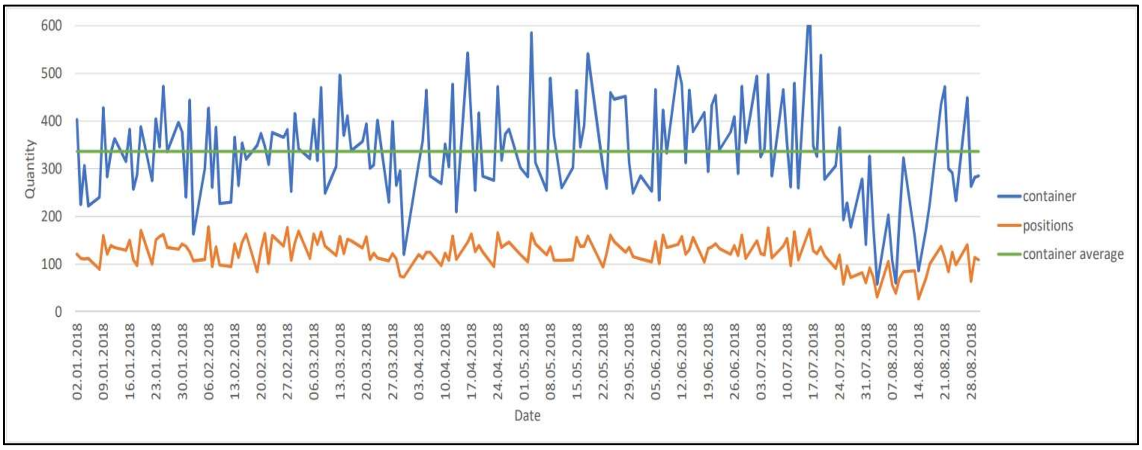


Figure 28: "Kommi" container transport volume January 2018 - August 2018

[87] the calculation of the error is in the Excel file: *Analysis_Kommi.xslx* in the "Teileliste" tab

At first view, it is noticeable that there are enormous fluctuations in transport volume on a daily basis. This fact was already known to warehouse management, but - also through this visualization of the problem - there are now concrete efforts to counteract. One possible improvement would be to increase the lead time for orders from 24 hours to 48 hours. This must be negotiated with the customers and could not be implemented at the time of completion of this master thesis yet.
Furthermore, in both processes under consideration, a significant drop in the curve from mid-July to mid-August can be observed. Both the suppliers and the end customer are on vacation in some departments or are driving back production to maintain the machines.

From this first analysis of the SAP data, the following results[88] can be listed:

- **<u>“NOT-Kommi”:</u>**

  - ➢ Part scope: 100
  - ➢ Container average per shift: 279
  - ➢ Total container (January – August): 46609

- **<u>“Kommi”:</u>**

  - ➢ Part scope: 321
  - ➢ Container average per day: 336
  - ➢ Container average per shift: 168
  - ➢ Total container (January – August): 62113

In addition, an important key figure was determined for each part number. Using the total number of containers per part number and the booking periods known from the SAP data, the average number of containers per part number and shift can be determined. This key figure is referred to as " container per day " in the calculations.

The result is not only a ranking of the individual parts in terms of their container volume per shift, but also the number of forklift movements required ("average carry per day"). Therefore, it is assumed that the forklift driver operates as often as possible with stacks of 3, then with stacks of 2 and only if no more containers are required they are moved individually.

The part number with the highest container volume per shift (high-runner) is ranked number 1. The higher the number in the ranking, the lower the container volume for this part number (low-runner).

[88] Excel file: *Analysis_NOT-Kommi.xslx* and *Analysis_Kommi.xslx* in the “History” and “Teileliste” tabs

Table 4 shows excerpts from the analysis of the "NOT-Kommi" parts with regard to the described key figures.

Table 4: Excerpt key figures

part number	container per day	ranking	average carry per day
BMW 6 875 104.3 LA	14,15	1	5
BMW 7 455 519	13,42	2	5
BMW 7 341 587.18	12,57	3	5
BMW 7 417 566.04	11,60	4	4
BMW 7 390 307	11,58	5	4
BMW 7 390 308	11,57	6	4
BMW 7 455 619	11,50	7	4
BMW 7 315 804	11,47	8	4
BMW 7 455 620	11,44	9	4
BMW 7 417 565.04	11,29	10	4
BMW 6 861 131.2 LA	9,09	11	4
BMW 7 446 413	6,99	12	3
BMW 7 446 414	6,98	13	3
BMW 7 315 803	5,73	14	2
BMW 7 296 362	5,05	15	2
BMW 7 296 361	5,04	16	2
BMW 6 861 114.2 LA	5,01	17	2
BMW 7 353 001	4,59	18	2
BMW 7 353 002	4,59	19	2
BMW 7 239 178	4,51	20	2
BMW 7 239 177	4,51	21	2
BMW 7 286 604	3,75	22	2
BMW 6 861 126.2 LA	3,49	23	2
BMW 6 861 125.2 LA	3,47	24	2
BMW 6 867 537.2 LA	3,38	25	2
BMW 7 231 959	3,02	26	2
BMW 7 231 960	3,01	27	2
BMW 6 860 841.04 X	2,96	28	1
BMW 7 286 603	2,90	29	1
BMW 6 867 538.2 LA	2,85	30	1

3.1.4 Storage Locations

The occupancy of storage locations plays an important role when it comes to increasing the efficiency of a warehouse. As presented in *chapter 2.1.2*, the Gate 12 warehouse is organised in the so-called chaotic block storage. Since the location is organised by logistics experts, the warehouse is already very efficient. The chaotic system is necessary because the selection of products passing through the warehouse changes daily. Even spontaneous special deliveries or short-term changes in the incoming or outgoing goods are not uncommon. A fixed allocation of storage locations to certain products would therefore be far too costly and time-consuming.

In spite of the chaotic system, however, simple basic principles are tried to be obeyed as far as the current circumstances allow. The forklift drivers know the containers and their content well enough to be able to judge whether they are high-runners or low-runners (assuming a high-runner has been in the assortment long enough).

It makes sense to keep the transport distances of high-runners as short as possible, since these distances are covered most frequently. Low-runners, conversly, should occupy the "inferior" storage locations, as the longer distance has to be covered less frequently. For a better understanding of the following explanations, see *Figure 29* in *chapter 3.1.5*.

For the "NOT-Kommi" process, this means the further left the storage location is in the warehouse layout, the shorter the transport distance. The reason for this is that the goods receipt, goods outgoing and preparation areas are also on the left-hand side.

The same considerations can be made for the actual "Kommi" process. It is better to store high-runner preferably on the left side (the high storage location numbers). The proximity to incoming and outgoing goods is also the strongest argument here, since the trucks should be loaded and unloaded as quickly as possible.

3.1.5 Comparison: Chaotic versus Optimized

In order to confirm the statements of the previous chapter, a storage situation that has resulted from the more or less chaotic system is compared with an optimized storage location occupancy. For this purpose, the SAP data provided represents a snapshot of the storage location occupancy from the 30 August 2018. The optimized situation was created with the help of the ranking (presented in *chapter 3.1.3*).

The "NOT-Kommi" part scope is considered. The chaotic allocation is visualized in *Figure 29* and the optimized version is shown in *Figure 30*. The different storage location allocations can also be found in the Excel file *Analysis_NOT-Kommi.xslx* in the “Teileliste” tab (Excel Layout displays are located in the tabs "chaotic allocation" and "optimized allocation"). The numbers in the orange fields correspond to the respective rankings of the parts.

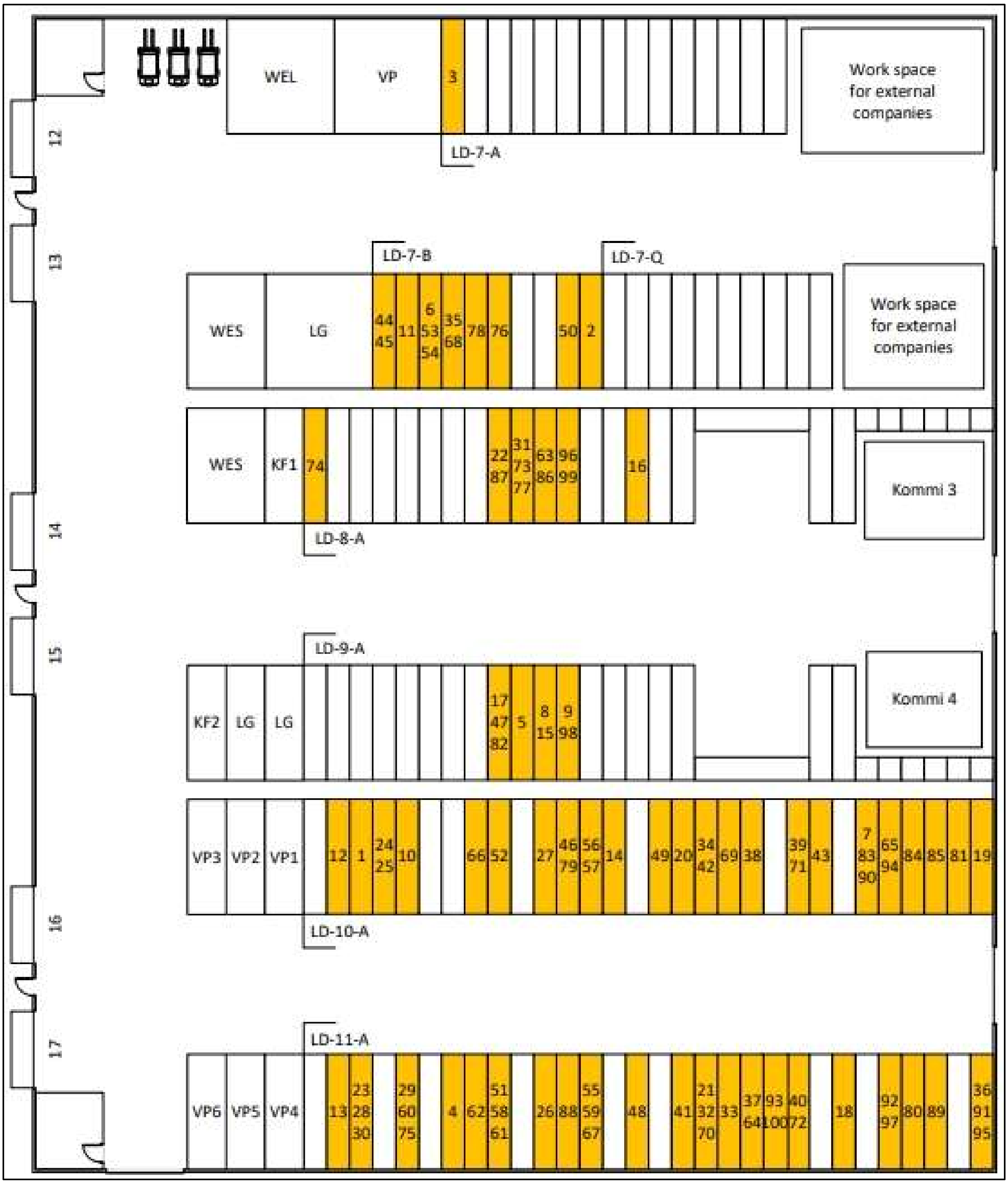


Figure 29: Chaotic storage location allocation

<u>Result of the chaotic allocation:</u>

The sum of the distances - of all average journeys made by the truck during a shift - for the actual "NOT-Kommi" process is **8770 meters**.

The time required for this average calculation is **3h 19min 06sec**. The time calculation also takes into account the activities carried out such as storage and retrieval (reference to *chapter 3.1.6*).

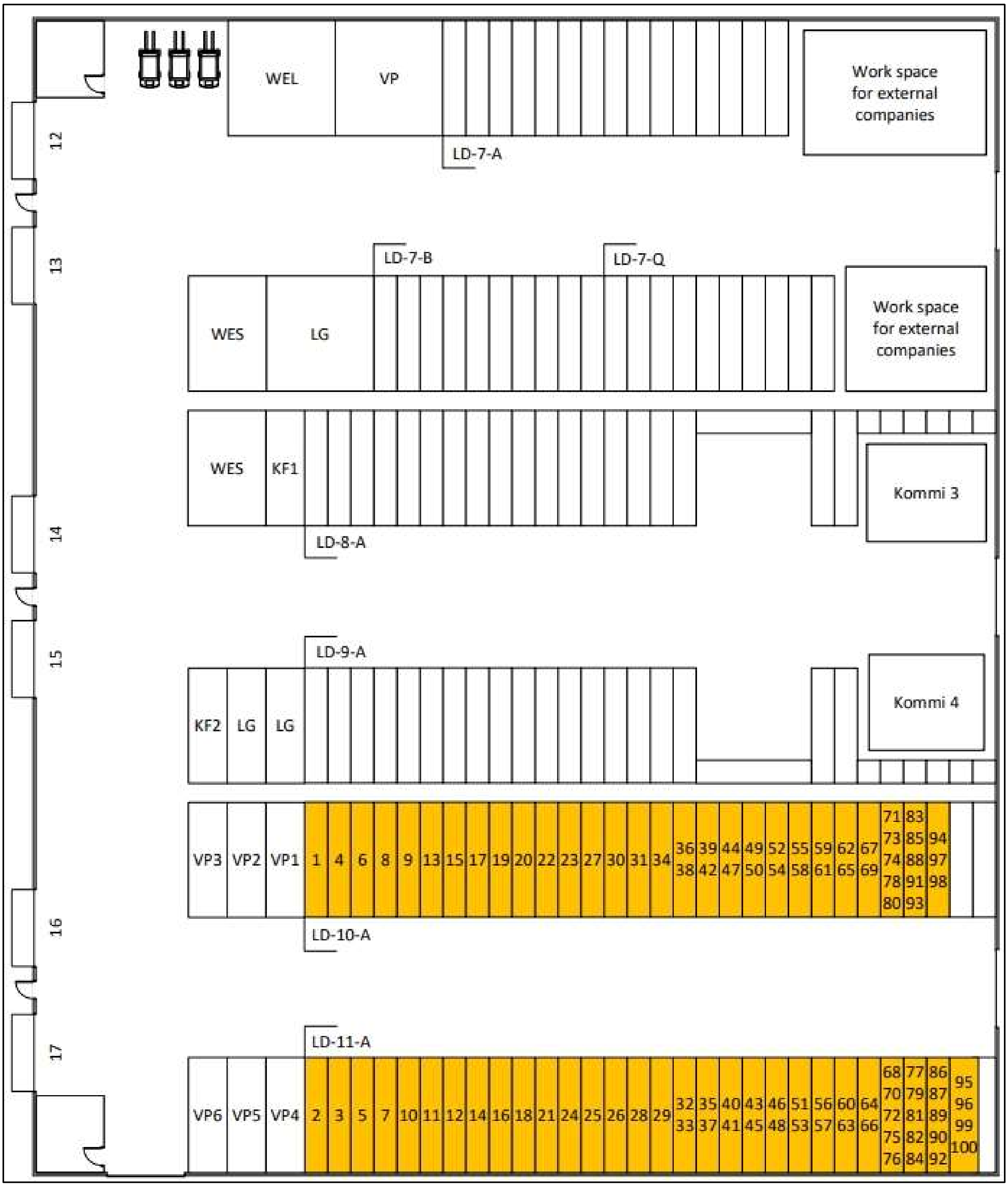


Figure 30: Optimized storage location allocation

Result of the optimised allocation:

The sum of the distances - of all average journeys made by the truck during a shift - for the actual "NOT-Kommi" process is **5026 meters** (reference to *chapter 3.1.6)*.

The required time for this average calculation is **2h 55min 46sec**. The time calculation also takes into account the activities carried out such as storage and retrieval but not the inspection process (reference to *chapter 3.1.6* and 3.1.7).

Comparison:

By optimising the allocation of storage locations, a saving of **3744 meters** can be achieved, according to the calculation. This corresponds to a reduction of **43%**. The process time is reduced by **23min 20sec** compared to the chaotic allocation. This time saving is equivalent to **12%**. The conclusion is that the routes usually have a much smaller impact on the process time than the activities carried out.[89]

3.1.6 Transport Distances

The basis for determining the transport routes and their distances is a true-to-scale layout of warehouse Gate 12 which was created in Excel. Since this layout is no longer up-to-date in some details, a new layout (only for the visual presentation) was created with the help of Microsoft Visio. This has already been presented (in *Figure 6*) and appears several times in this master thesis in modified form. For the fact that the true-to-scale layout is not designed for A4 format, the reader is referred to the appendix (Excel File *Layout_Gate_12.xlsx*).

The measured distances can be found in the Excel files *Analysis_NOT-Kommi.xslx* and *Analysis_Kommi.xslx* in the tab "Distance & Time". As an example, *Table 5* shows excerpts of the distance measurements between the storage locations in LD-10-A and the preparation place in the "NOT-Kommi" area. The number of curves per route are also recorded.

Table 5: Excerpt distance measurement

storage location to preparation area	distance [m]	curves
LD-10-A-08	32,3	1
LD-10-A-09	31,2	1
LD-10-A-10	30,1	1
LD-10-A-11	29,0	1
LD-10-A-12	27,9	1
LD-10-A-13	26,8	1
LD-10-A-14	25,7	1
LD-10-A-15	24,6	1

[89] confirmed by the experience of the Jerich logistics specialists

3.1.7 Practical Time Study

Initially it must be mentioned that the REFA time study described in *chapter 2.3* was simplified for the purposes of this master thesis.

The process duration is calculated in order to determine the necessary personnel requirements. If the duration and the resulting differences are known, it can be derived how many employees are required for the execution of the processes.

To calculate the process duration, all activities the considered process consists must be examined. If the duration of the individual activities is known, these only have to be added up to determine the total duration.

The duration of the individual activities is measured with a stopwatch. The following points must be considered before the measurements can be performed:

- Which activities are to be measured?
- Prepare measurement protocol
- Perform multiple measurements
- Good communication (with the employee measured at work) is important

In the course of this master thesis, the necessary measurements were made together with an employee (forklift driver) - in the presence of the warehouse management.

The results of the time study are listed in *Table 6*.

Table 6: Time study protocol

Time Study Forklift Truck

	Distance [m]	with load [sec] Measurement 1	Measurement 2	Measurement 3	Average	Declaration
	1	1,88	2,16	2,07	**2,04**	including acceleration/deceleration
	5	4,7	4,31	4,62	**4,54**	including acceleration/deceleration
	10	6,77	7,03	6,82	**6,87**	including acceleration/deceleration
	20	10,36	9,97	10,55	**10,29**	including acceleration/deceleration
	50	17,09	16,6	17,02	**16,90**	including acceleration/deceleration
	curve addition	3,38	2,86	2,91	**3,05**	per curve
	10	3,14	3,09	3,05	**3,09**	at full speed

	Distance [m]	without load [sec] Messung 1	Messung 2	Messung 3	Average	Declaration
	1	1,54	2,21	2,13	**1,96**	including acceleration/deceleration
	5	4,07	4,8	4,06	**4,31**	including acceleration/deceleration
	10	6,16	6,37	6,49	**6,34**	including acceleration/deceleration
	20	10,15	9,46	9,67	**9,76**	including acceleration/deceleration
	50	15,93	15,45	15,96	**15,78**	including acceleration/deceleration
	curve addition	2,22	2,33	2,4	**2,32**	per curve
	10	2,72	2,85	2,84	**2,80**	at full speed

	Activities	[sec] Measurement 1	Measurement 2	Measurement 3	Average	Declaration
A	lifting	9,87	9,57	9,8	**9,75**	for 3 meters (average stacking height)
B	sinking	9,2	9,23	9,19	**9,21**	for 3 meters (average stacking height)
C	stock removal	19,02	40,34	38,58	**32,65**	remove container from storage (complete)
D	put into storage	23,59	26,61	27,03	**25,74**	store container in warehouse (complete)
E	positioning	7,05	10,51	11,46	**9,67**	exact positioning of the container (no stroke)
F	pickup	10,66	8,23	8,63	**9,17**	picking up the container from the floor (no stroke)
G	destacking of 2	9,86	8,45	8,68	**9,00**	unstack stack of 2 containers
H	stack of 2	10,14	10,72	10,38	**10,41**	stacking a stack of 2 containers
I	destack 3	25,46	21,45	22,16	**23,02**	unstack stacks of 3 containers
J	stacking of 3	24,98	28,71	25,75	**26,48**	stacking a stack of 3 containers
K	battery change	355,56			**355,56**	battery change complete

Time Study Inspection Process

	Activities	[sec] Measurement 1	Measurement 2	Measurement 3	Average	Declaration
L	scan label	9,23	12,02	10,74	**10,66**	scanning input label
M	take component					remove component from container
N	inspection					visual inspection: part to label
O	component back					return component to container
P	print VDA	29,27	31,59	33,03	**31,30**	print Label
Q	attach VDA					attach label
R	entire process	38,50	43,61	43,77	**41,96**	duration L-Q

The measured times for the different distances do not cover the entire spectrum of the occurring lengths. The duration for lengths that lie between or above the defined distances of the time study is interpolated linearly.

The diagrams (in *Figure 31* and *Figure 32*) show that this results in a plausible curve that is adequately accurate for the calculations.

As the individual activities of the inspection process partly merge into each other, they were grouped together in activity groups. Thus, an inspection duration is also available for the actual "Kommi" process, since the forklift driver does not have to print or attach a VDA label here.

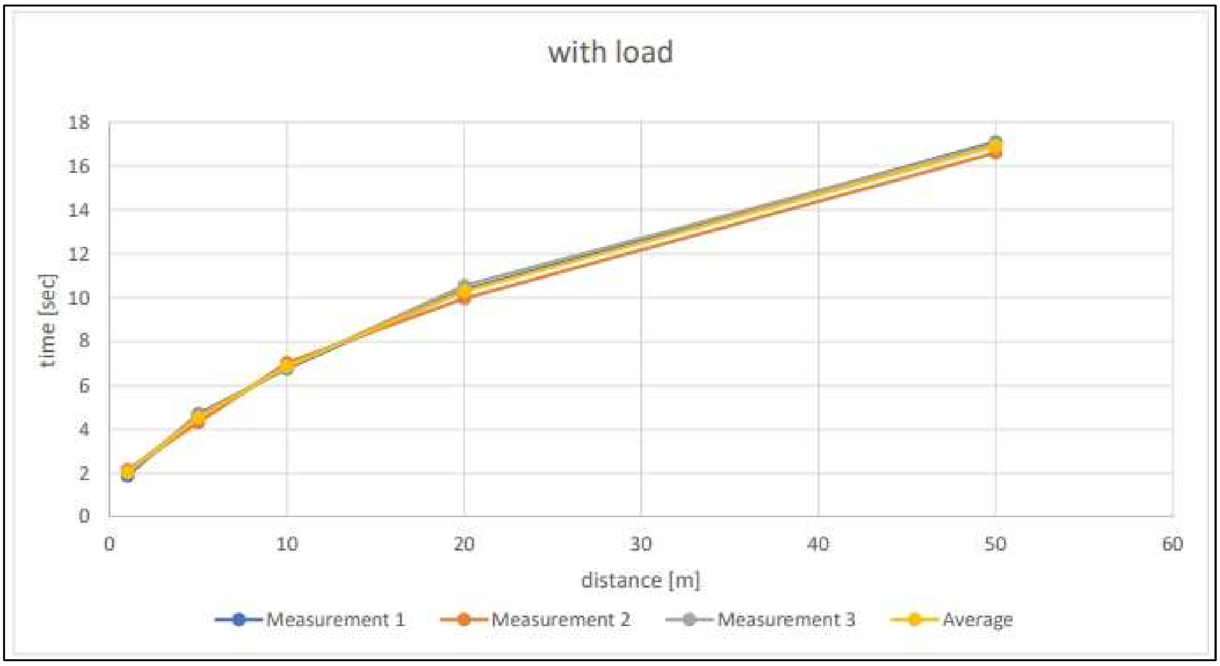


Figure 31: Time-distance interpolation with load

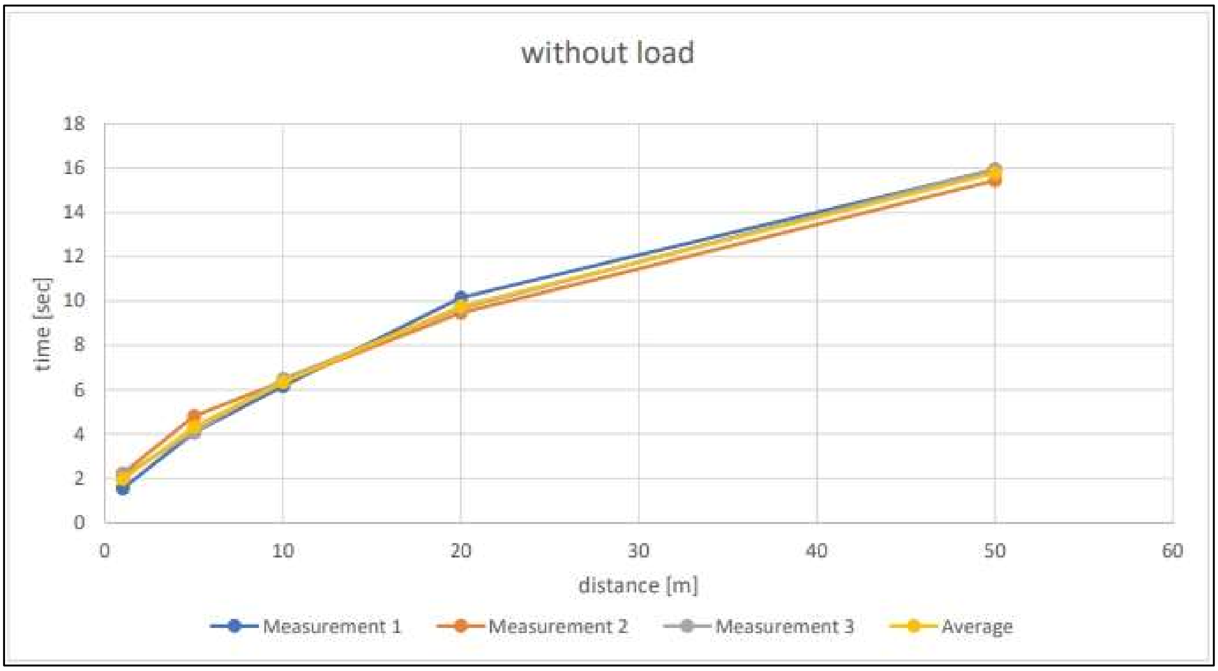


Figure 32: Time-distance interpolation without load

The times determined for the various activities were checked by the warehouse management and compared with their empirical values or measurements. The specified duration for the current inspection process (default: 45 seconds) could also be verified with an average of 41.96 seconds.

The shown data can be found in the appendix in the Excel file *Time_Study_Measures.xlsx*.

3.1.8 Process Times

In the previous chapters, all necessary elements were developed to determine the process times for the different workflows. To achieve results that are as realistic as possible, it is important that the investigated processes are modelled without gaps.

For example, once the forklift has placed an empty container on the designated area, it cannot immediately begin to remove a source container from storage. In the model - as well as in reality - the forklift must first be moved from the empty container area to the storage location of the source container. Since all calculations are based on average values, the average distance between the storage locations of the area in view is used to overcome this gap.

Constraints:

- An exact assignment of a particular employee to a particular activity is not possible. Not all tasks of the employees are considered in the models, just those which are affected by changes with the implementation of the new technology. If, for example, a forklift driver is busy loading or unloading a truck, another driver takes over the supply of source containers for commissioning.

- The models describe only an average effort on the basis of 8 months.

- Unpredictable events (waiting times, delivery delays, special trips, coffee or toilet breaks, daily constitution of employees etc.) are only taken into account by an estimation factor - in the analyses referred to as obstruction factor[90]. The obstruction factor was set to 25% together with warehouse management. The inspection time is not affected by this factor.

Assumptions:

- In order to filter out the differences between the actual and target situation as precisely as possible, both situations should be described under identical conditions. Therefore, the optimized storage locations are used for the analysis, as it was shown - in *chapter 3.1.5* - that different transport routes have only a minor effect on the process duration. For the "Kommi" process, an optimized storage location assignment[91] was created with the help of the rankings of the components, just as for the "NOT-Kommi" process.

- Although the battery change was recorded in the time study, it is not explicitly included in the calculations, as this activity does not have to be performed in each shift. This activity should be included in the obstruction factor.

---

[90] Vgl. ZWICKL,M. (2011), S. 67

[91] the optimized assignment as well as a visualization of the actual allocation is in the Excel file: *Analysis_Kommi.xlsx*

The calculation of the total process times is very complex, that is why only an explanatory example and the results are given here. The calculation in detail can be viewed in the Excel files *Analysis_NOT-Kommi.xlsx* and *Analysis_Kommi.xlsx*.

Example:
In this example, the part with ranking number 1 is used for the target "NOT-Kommi" process. Table 7 shows the calculation procedure for a container of the most intensive part of the "NOT-Kommi" process.

Table 7: Calculation example process time

Activity	Distance [m]	Time [sec]
activity: C (stock removal)		32,65
distance: 19,3 meters (with load)	19,3	10,05
curves: 2 (with load)		6,10
activity: E (positioning)		9,67
storage place to test bench sink	19,3	58,47
distance: 12,1 meters (without load)	12,1	7,09
curves: 4 (without load)		9,27
test bench sink to source	12,1	16,35
inspection process (target)		45,00
activity: F (pickup)		9,17
distance: 21,2 meters (with load)	21,2	10,56
curves: 3 (with load)		9,15
activity: D (put into storage)		25,74
test bench source to preparation area	21,2	54,62
distance (average): 25 meters (without load)	25	10,76
curves: 1 (without load)		2,32
preparation area to storage place	25	13,08
Obstruction Factor		25%
inspection		45,00
storage place to test bench sink	19,3	73,09
test bench sink to source	12,1	20,44
test bench source to preparation area	21,2	68,28
preparation area to storage place	25	16,35
Summary	**77,6**	**223,16**

Comments:
In order to obtain the result per shift, these values are multiplied with the "*average carry per day"*, as the forklift truck is capable of transporting up to three containers simultaneously. The only exception is the inspection time, which is multiplied by the average number of containers, as each container must be inspected.

The results of the process time calculations also contain the results for the respective transport distances. *Table 8* shows the results for the actual and target "NOT-Kommi" processes.

Table 8: Results "NOT-Kommi" processes

Obstruction Factor	**25%**

Actual Situation optimized "NOT- Kommi"

	1 shift	
	Distance [m]	Time [sec]
inspection time		03:15:11
preparation area to storage place & back	5026	03:39:42
Summary	**5026**	**06:54:53**

Target Situation optimized "NOT-Kommi"

	1 shift		
	Distance [m]	Time [sec]	Difference to Actual per shift
inspection time		03:29:19	00:14:08
storage place to test bench sink	4106	02:43:23	
test bench sink to source	1547	00:43:28	02:12:33
test bench source to preperation area	2710	02:25:24	
preparation area to storage place	3195	00:34:47	00:34:47
Summary	**11557**	**09:56:21**	**03:01:28**

Table 9: Results "Kommi" processes

Obstruction Factor	**25%**

Actual Situation optimized "Kommi"

	2 shifts		1 shift	
	Distance [m]	Time [sec]	Distance [m]	Time [sec]
inspection time		00:59:45		00:29:53
storage place to commissioning	4981	03:38:07	2491	01:49:03
source container to storage place	1172	00:56:48	586	00:28:24
empty containers	5702	02:11:43	2851	01:05:52
storage place to storage place	3699	00:55:00	1850	00:27:30
Summary	**15555**	**07:41:38**	**7777**	**04:20:41**

Target Situation optimized "Kommi"

	2 shifts		1 shift		
	Distance [m]	Time [sec]	Distance [m]	Time [sec]	Diff to Actual per shift
inspection time		04:12:11		02:06:05	01:36:13
storage place to test bench sink	6558	04:20:29	3279	02:10:15	
test bench sink to source	2216	01:02:17	1108	00:31:09	02:05:58
test bench source to commissioning	9010	02:27:17	4505	01:13:38	
source container to storage place	1172	00:56:48	586	00:28:24	00:00:00
empty containers	5702	02:11:43	2851	01:05:52	00:00:00
storage place to storage place	3699	00:55:00	1850	00:27:30	00:00:00
Summary	**28358**	**11:53:34**	**14179**	**08:02:52**	**03:42:11**

Table 9 presents the results for the actual and target “Kommi” processes.

3.1.9 Overview Actual Situation

Here a compact overview of the current situation in warehouse "Gate 12" should be given. *Figure 33* shows the areas in which the processes under investigation take place. The routes of the forklift that are affected by changes during the implementation of the prototype test bench are also shown. Paths that do not change (see *Table 8* and *Table 9*) are not depicted.

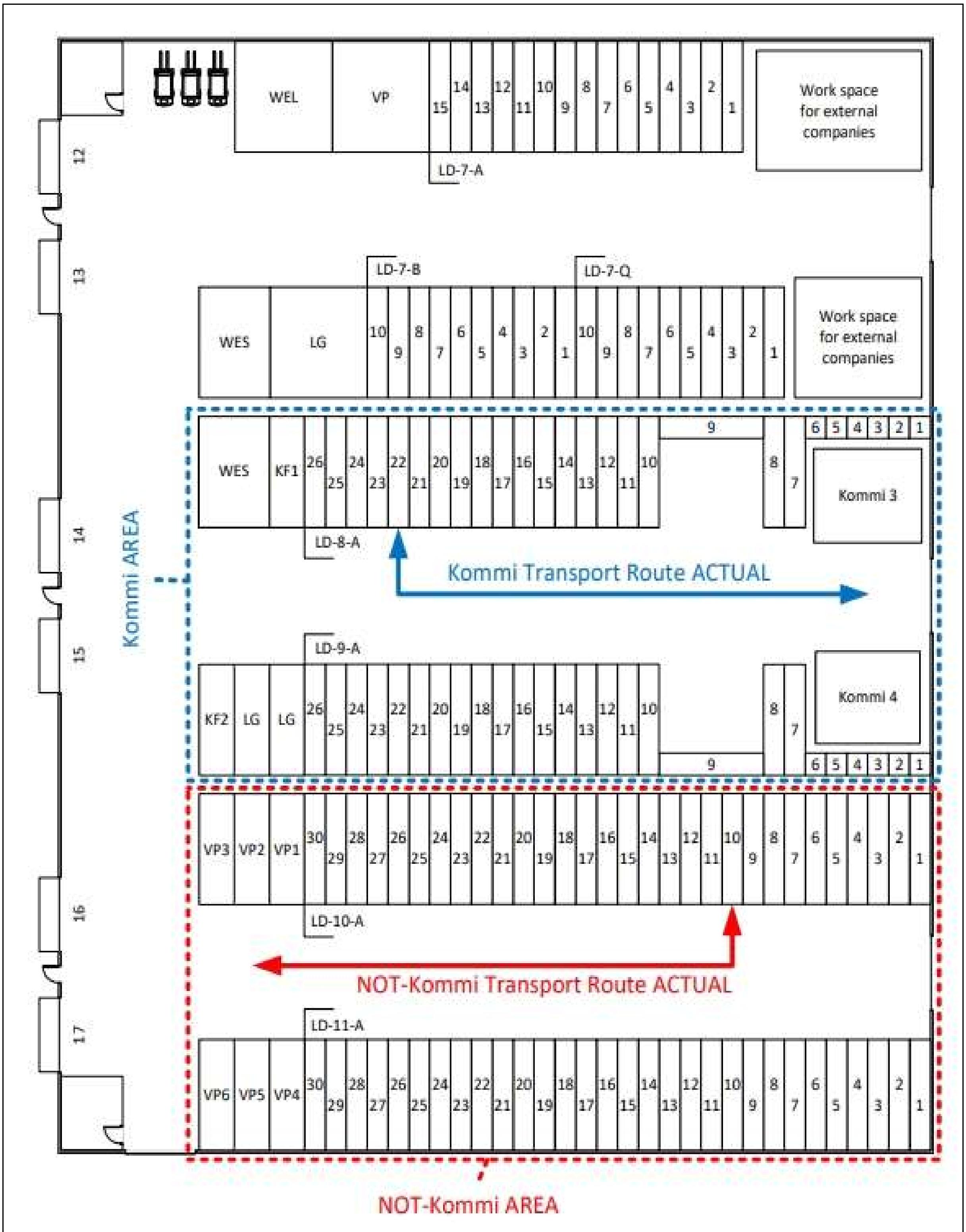


Figure 33: Overview actual situation

3.1.10 Overview Target Situation

In direct contrast to the overview of the actual situation, Figure 34 shows the intended target situation. As in the previous illustration, transport routes that remain unchanged are not shown here.

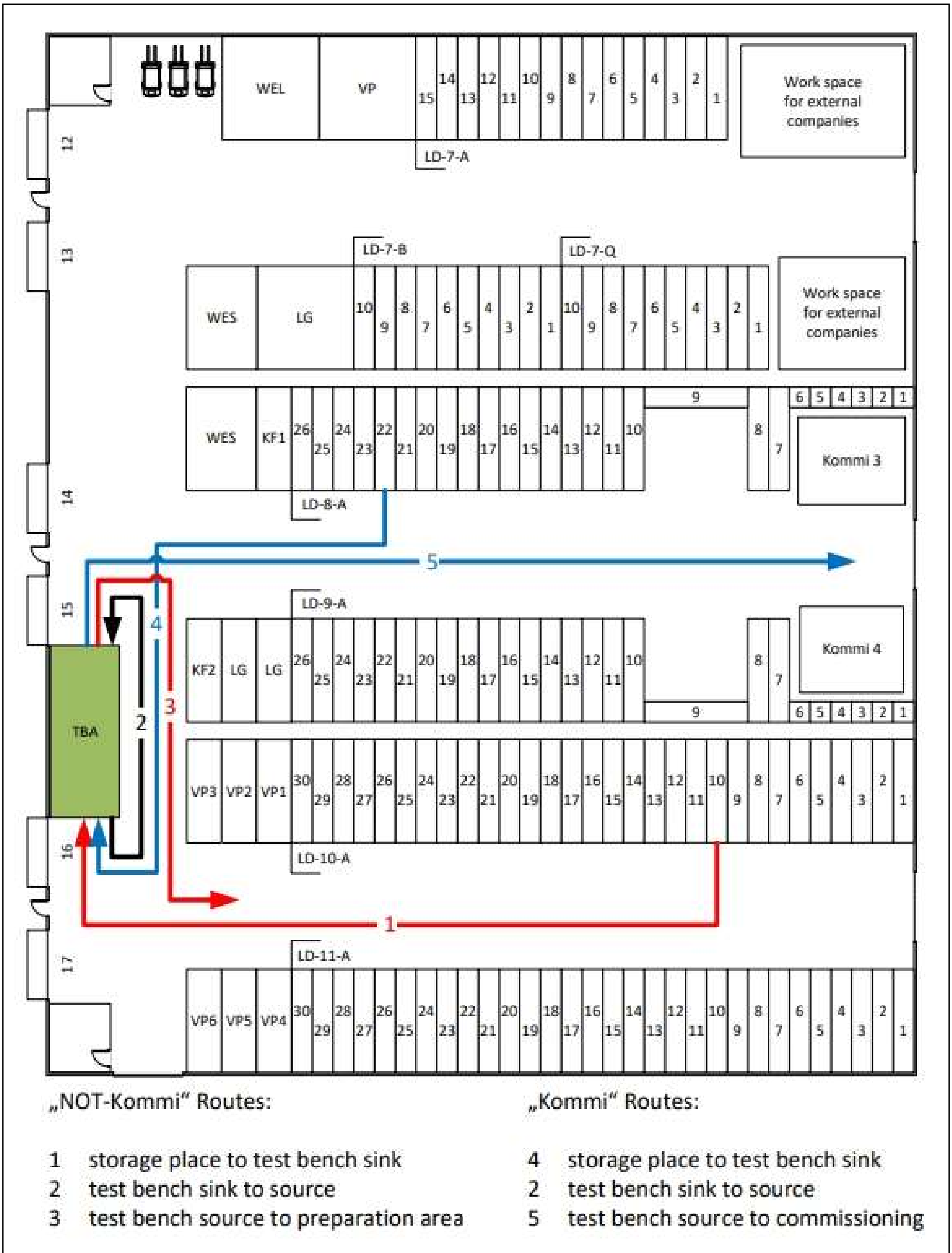


Figure 34: Overview target situation

The reasons for the positioning of the test bench area will be discussed here. During an on-site walk-through of Hall "Gate 12" - with the warehouse management and project management - the advantages and disadvantages for various areas were discussed. The decision for the location - as shown in *Figure 6* and *Figure 34* - was made on the basis of the numerous advantages that this space offers.

Advantages:

- Safest environment for the employee at the test bench
  - ➢ no risk of container stacks falling over
  - ➢ no risk from forklift traffic due to correct design of the workplace (see *Figure 16*)
- Proximity to goods receipt, outgoing goods and preparation areas
- Proximity to both process areas considered
- Storage space does not have to be reduced
- Minimum effort for conversion
- Good overview of the main corridor
- Good accessibility for forklifts from three sides

Disadvantages:

- Gate 15 and gate 16 are in the immediate near of the feed and discharge of the conveyor system.
- Strong fluctuations in the lighting of the area (gates, overhead lighting, roof windows etc.). For large components with smooth surfaces, this can lead to reflections which can cause problems in image processing.

The discovered disadvantages can be compensated with simple measures. The affected gates can be avoided as far as possible and adjustable light protection against reflections is planned on the test bench.

3.1.11 Determination of the Area Costs

As the project progressed and after the selection of the test bench area, there was no need to reduce existing storage space - contrary to the initial assumption. This fact can be seen from a comparison of *Figure 33* and *Figure 34*. As a result, the total capacity of the warehouse does not decrease and there is no reduction in potential sales.

The costs per square meter are provided by the controlling department: **3,20 €/m²**. This corresponds to the operating costs of the warehouse per square meter.

Since at the time of the economic analysis no detailed plans of the conveyor system are available, a maximum area requirement is estimated: **100m²**.

With appropriate optimization, probably $60m^2$ - $70m^2$ are completely sufficient, but in order to not evaluate the situation too optimistically, this value is chosen for the calculations. Furthermore, the area costs of this magnitude have only a minor impact on the economic success of the project.

3.1.12 Determination of the Personnel Costs

The personnel costs are of much greater importance for the project in comparison to the area costs. An employee in the warehouse costs approximately 3.300 €/month.

For the "NOT-Kommi" process, it is easier to make the statement that no additional personnel costs are required compared to the actual situation. Although a calculated additional expenditure of almost 3 hours results for an average shift, this can be achieved with the current personnel (2 employees for the "NOT-Kommi" process). Even common peaks can still be covered. The obstruction factor (25%) also ensures a certain safety margin.

There are also no additional personnel costs for the "Kommi" process, but here the statement is more difficult to understand. The considerable additional expenditure of more than 1.5h for the testing time is due to the fact that no label has to be printed and affixed in the current process. The additional transport costs are similar to those for the "NOT-Kommi" process. Since the tasks of the employees involved in the "Kommi" process overlap with other processes, it is difficult to estimate the personnel expenditure.
The determination of personnel costs has been clarified with the warehouse management and so it can be assumed, for the economic considerations, that no additional personnel is necessary for the execution of the target processes.

From June 2019 it is planned to reduce the number of employees by one and to reduce a forklift truck by increasing usage of pallet trucks in combination with the conveyor system.

3.2 Economical Solutions

If all the necessary values for the investment calculation are known, the required key figures can be determined. As presented in *chapter 2*, the calculation methods used in the following, are models that are intended to provide the investor with clear key figures as a decision-making aid. The economic useful life is **5 years**[92] and the calculatory interest rate is **7,8%**[93].

3.2.1 Statement of Costs

Here a clear listing of the costs of the project optical part identification is given. Since dynamic methods are used, the time of the payment is also important. In the following the respective cost elements are listed as well as the information, at which time each part of it is paid. It is common for payments to be made in stages over the duration of the project. A detailed presentation of the costs as well as the cash flow can be seen in the Excel file *Economic_Analysis.xlsx* included in the appendix.

Costs:

- **Hardware: 85.000€**
  - 30% June 2018 25.500€
  - 30% December 2018 25.500€
  - 30% March 2019 25.500€
  - 10% June 2019 8.500€

- **R&D[94]: 35.000€**
  - 30% June 2018 10.500€
  - 30% December 2018 10.500€
  - 30% March 2019 10.500€
  - 10% June 2019 3.500€

- **Conveying System: 40.000€**
  - 100% June 2019 40.000€

- **Training costs: 22.800€**
  - 1/3 February 2019 7.600€
  - 1/3 April 2019 7.600€
  - 1/3 June 2019 7.600€

- **Area costs p.a.: 3.840€**
  - Monthly from January 2019 320€

[92] predefined by Jerich project management
[93] predefined by the controlling department
[94] Research and Development

3.2.2 Savings Potential

No revenues are generated with the test bench, but savings can be realized. For the key figures calculated here, this makes no difference as revenues and savings have the same effect on the cash flow. A detailed presentation of the savings potential as well as the cash flow can be seen in the Excel file *Economic_Analysis.xlsx* included in the appendix.

Savings:

- **200% control p.a.: 25.200€**
  - Monthly from June 2019 2.100€
- **Complaints p.a.: 26.400€**
  - Monthly from June 2019 2.200€
- **Staff + forklift p.a.: 48.000€**
  - Monthly from June 2019 4.000€

3.2.3 Net Present Value

A detailed cash flow was created and the NPV calculated *Table 10*[95] shows the result in a compact form.

Table 10: Net present value

period	a	e	Cash Flow	NPV
0	€ 72.000,00	€ 0,00	-€ 72.000,00	-€ 72.000,00
1	€ 114.640,00	€ 58.100,00	-€ 56.540,00	-€ 52.448,98
2	€ 3.840,00	€ 99.600,00	€ 95.760,00	€ 82.403,68
3	€ 3.840,00	€ 99.600,00	€ 95.760,00	€ 76.441,26
4	€ 3.840,00	€ 99.600,00	€ 95.760,00	€ 70.910,26
5	€ 3.840,00	€ 99.600,00	€ 95.760,00	€ 65.779,46
				€ 171.085,69

At the end of the useful life of 5 years, the capital value of the investment is clearly positive. As explained in *chapter 2.2.5.3*, a positive net present value indicates the absolute advantage of an investment (the higher the better).

In case of the optical part identification project, the NPV (171.085,69€) provides a recommendation for the investment.

[95] The Excel file *Economic_Analysis.xlsx* contains the detailed cash flow and the calculation for the NPV

3.2.4 Dynamic Amortisation Period

The calculation of the dynamic amortisation time is basically the same as the calculation of the net present value. Only the question which is addressed to the calculation is different. While the NPV answers the question about the absolute advantage of an investment, the dynamic amortisation period indicates the time span after which the investor received his money back.

Table 11[96] shows a calculation for the dynamic amortisation period.

Table 11: Dynamic amortisation period

	2018 Dez.	2019 Dez.	2020 Dez.	2021 Dez.	2022 Dez.	2023 Dez.
t	0	1	2	3	4	5
Cash Flow	-€ 72.000,00	-€ 56.540,00	€ 95.760,00	€ 95.760,00	€ 95.760,00	€ 95.760,00
NPV	-€ 72.000,00	-€ 52.448,98	€ 82.403,68	€ 76.441,26	€ 70.910,26	€ 65.779,46
Cumulated	-€ 72.000,00	-€ 124.448,98	-€ 42.045,30	€ 34.395,97	€ 105.306,23	€ 171.085,69

As can easily be seen from the yellow marking, the amortisation period must be somewhere between the second and third year.

A more precise determination can be made with the help of linear interpolation:

Interpolated dynamic amortisation time: **2,55 years**

[96] The Excel file *Economic_Analysis.xlsx* contains the detailed cash flow and the calculation for the dynamic amortisation period

3.2.5 Interpretation Economic Analysis

The calculated net present value clearly shows the absolute advantage of the investment in the pilot project optical part identification. If the prototype is successfully implemented in day-to-day business, an investment in additional test benches - in order to integrate the technology at all locations active in the automotive industry - is also recommended. The reason given for this is that R&D costs for additional test benches are no longer necessary as well as the fact that the savings potential at other locations is similar[97].

The calculated dynamic amortisation period cannot be evaluated absolutely. The automotive industry is fast-moving, especially at a time of change in the industry with regard to electric mobility. In general, the attempt is to amortise investments in the automotive sector in less than three years[98]. The dynamic amortisation time for the optical part identification project also meets this recommended criterion with around 2,55 years.

When determining and analysing the data, care was taken to give a realistic view of the facts as possible. The assumptions were made in such a way, that the impression is not too optimistic to be able to verify the data at a later control.

In the end the decision must be made by the investor. Not only monetary aspects should be considered, but also non-monetary aspects such as customer satisfaction, competitiveness, safety and sustainability.

[97] statement Jerich project management
[98] no regulation but an industry standard recommendation

4 Summary and Outlook

The delivery quality at Jerich International is to be improved, with the background of addressing the company's zero-error strategy and reducing costs. Currently, the manual inspection process can lead to incorrect labelling due to human error. Therefore, the company is investing in the development of an innovative technical support solution - a test bench for optical part identification. In a pilot project, the prototype of the test stand is developed and an optimal implementation in day-to-day business is prepared.

The main objective of this master thesis is the economic analysis of the project "optical part identification" on the basis of dynamic calculation models of the investment calculation. To estimate the input values for these calculations as accurately as possible, the effects and differences of the new processes are elaborated. The actual situation and the target situation are examined with regard to the change of working conditions, transport routes and process times. From this, important cost drivers such as area costs and personnel costs are derived.

It can be shown that an implementation of the test bench does not lead to a significant increase in operating costs. In contrast, an improvement in the inspection process offers considerable savings potential.

The net present value is clearly positive at around 171,000€ (useful life 5 years, calculatory interest rate 7.80%). From an economic point of view, this provides an absolute advantage of the investment. The dynamic amortisation period is 2,55 years and provides an acceptable value for this key figure.

The results of this master thesis therefore indicate a clear recommendation for the investment.

The timeframe of this work prevents a check of the determined key figures. As an outlook for further investigations, it is therefore recommended to monitor and control the data after completion of the optical part identification project. Furthermore, the results will be submitted for a possible funding of the Austrian FFG (Forschungsförderungsgemeinschaft). The effect of such funding also offers potential for further investigation.

List of References

JERICH INTERNATIONAL: Homepage, https://www.jerich.com, viewed on 19.12.2018

JERICH PROJECT MANAGEMENT: Project documents "optical part identification", Gleisdorf 2018

IVII PROJECT MANAGEMENT: Project documents "optical part identification", Gleisdorf 2018

VERBAND DER AUTOMOBILINDUSTRIE: Global Transport Label, https://www.vda.de, (VDA 4994, Version 1.1), viewed on 04.08.2018

WIKIPEDIA: QR-Code, https://en.wikipedia.org/wiki/QR_code#, viewed on 08.01.2019

ZWICKL, M.: Erarbeitung eines Konzepts für die Automatisierung des innerbetrieblichen Transportwesens in einem Großpresswerk, Diplomarbeit, Graz 2011

KOETHER, R.: Taschenbuch der Logistik, 5. Auflage, München 2018

MÜLLER, D.: Investitionsrechnung und Investitionscontrolling, 2. Auflage, Berlin 2019

WIENDAHL, H.: Betriebsorganisation für Ingenieure, 8. Auflage, München 2014

MUCHNA, C.; BRANDENBURG, H.; FOTTNER, J.; GUTERMUTH, J.: Grundlagen der Logistik, Wiesbaden 2018

POGGENSEE, K.: Investitionsrechnung: Grundlagen – Aufgaben - Lösungen, 3. Auflage, Wiesbaden 2015

GÖTZE, U.: Investitionsrechnung: Modelle und Analysen zur Beurteilung von Investitionsvorhaben, 7. Auflage, Heidelberg 2014

KERN, W..: Investitionsrechnung, Stuttgart 1974

KRUSCHWITZ, L.: Investitionsrechnung, 14. Auflage, München 2014

HERING, E.: Investitions- und Wirtschaftlichkeitsrechnung für Ingenieure, Wiesbaden 2014

SCHÖNBOHM, A.; ZAHN, A.: Corporate capital budgeting: Success factors from a behavioural perspective, Beiträge zur Controlling Forschung, No. 21; Kaiserslautern 2012

KESTEN, R.: Fitness-Check "Investitionsrechnung und Unternehmensbewertung": Ergebnisse einer empirischen Untersuchung, Arbeitspapiere der Nordakademie, No. 2006-01, Elmshorn 2006

GRIEMERT, S.: Entscheidungsmodell für den wirtschaftlichen RFID-Einsatz, Wissenschaftliche Schriften des Fachbereichs Betriebswirtschaft, No. 2-2010; Koblenz 2010

REFA: Industrial Engineering: Standardmethoden zur Produktivitätssteigerung und Prozessoptimierung; 2. Auflage, Darmstadt (2015)

BERTAGNOLLI, F.: Lean Management: Einführung und Vertiefung in die japanische Management-Philosophie, Wiesbaden 2018

List of Figures

List of Tables

List of Abbreviations

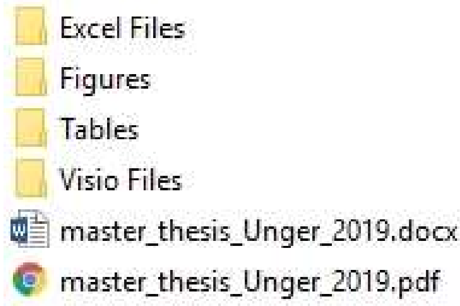
2D	Two Dimensional
AG	Aktiengesellschaft
BMW	Bayerische Motoren Werke
CEO	Chief Executive Officer
ERP	Enterprise-Resource-Planning
etc.	et cetera
EUR	Euro
FFG	Forschungsförderungsgemeinschaft
FIFO	First In-First Out
HMI	Human-Machine Interface
IT	Information Technology
JIT	Just in Time
KLT	Kleinladungsträger
LIFO	Last In-First Out
MTM	Methods-time Measurement
NPV	Net Present Value
OEM	Original Equipment Manufacturer
p.a.	per anno
QR-Code	Quick Response Code
R&D	Research and Development
TBA	Test Bench Area
URL	Uniform Resource Locator
USA	United States of America
VDA	Verband der Automobilindustrie
VW	Volkswagen

List of Equations

Appendix

Appendix 1: Digital Data

The enclosed USB stick contains all relevant data of this master thesis. The data is structured as follows:



The folder *Excel Files* contains all performed calculations as well as the provided *layout Gate 12*.

The folder *Figures* contains all used figures.

The folder *Tables* contains all the tables listed.

The folder *Visio Files* contains the original data of the creation.