TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Economics

Lean logistics in axle production

Master Thesis

Study programme: N0413A050030 International Management
Author: **Bc. Linda Phanová**
Thesis Supervisors: Ing. Eva Štichhauerová, Ph.D.
Departmens of ussines Administration and Management

Liberec 2022

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Economics

Master Thesis Assignment Form

Lean logistics in axle production

Name and surname:	**Bc. Linda Phanová**
Identification number:	E20000359
Study programme:	N0413A050030 International Management
Assigning department:	Departmens of ussines Administration and Management
Academic year:	**2021/2022**

Rules for Elaboration:

1. Theoretical background in the field of lean management.
2. Introduction and characteristics of the selected company.
3. Analysis of the current state of the company.
4. Identification of critical points.
5. Proposal of measures based on the results of the analysis.
6. Summary and evaluation of the results obtained.

Scope of Graphic Work:
Scope of Report: 65 normostran
Thesis Form: printed/electronic
Thesis Language: English

List of Specialised Literature:

- BRADLEY, James R., 2012. *Business Expert Press*, LLC. ISBN 13: 978- 1- 60649- 265- 9.
- CHARRON, Rich, H. James HARRINGTON, Frank VOEHL a Hal VIGGIN, 2015. *The Lean Management Systems Handbook*. Boca Raton: CRC Press. ISBN 978-1-4987-0529-5.
- KING, Peter L. a Jennifer S. KING, 2015. *Value Stream Mapping for the process industries: creating a roadmap for lean transformation*. Boca Raton: CRC Press/Taylor & Francis Group. ISBN 9781482247688.
- LIKER, Jeffrey K., 2004. *The Toyota Way: 14 Management Principles from the World´s Greatest Manufacturer*. McGraw-Hill. ISBN: 0071392319.
- PROQUEST, 2021. *Databáze článků ProQuest* [online]. Ann Arbor, MI, USA: ProQuest. [Cit. 2021-09-01]. Dostupné z: http://knihovna.tul.cz
- SAYER, Natalie J., 2012. *Lean for dummies*. 2^{nd} ed. Hoboken N.J. Wiley. ISBN 9781118237724.
- SVOZILOVÁ, Alena, 2011. *Zlepšování podnikových procesů*. Praha: Grada Publishing. ISBN 978-80-247-3938-0.

Consultant: Bc. Tomáš Dvořák (Coordinator of logistics section-hall M1)

Thesis Supervisors: Ing. Eva Štichhauerová, Ph.D.
Departmens of ussines Administration and Management

Date of Thesis Assignment: November 1, 2021
Date of Thesis Submission: August 31, 2023

L.S.

doc. Ing. Aleš Kocourek, Ph.D.
Dean

Ing. Eva Štichhauerová, Ph.D.
Head of Department

Liberec November 1, 2021

Declaration

I hereby certify, I, myself, have written my master thesis as an original and primary work using the literature listed below and consulting it with my thesis supervisor and my thesis counsellor.

I acknowledge that my master thesis is fully governed by Act No. 121/2000 Coll., the Copyright Act, in particular Article 60 – School Work.

I acknowledge that the Technical University of Liberec does not infringe my copyrights by using my master thesis for internal purposes of the Technical University of Liberec.

I am aware of my obligation to inform the Technical University of Liberec on having used or granted license to use the results of my master thesis; in such a case the Technical University of Liberec may require reimbursement of the costs incurred for creating the result up to their actual amount.

At the same time, I honestly declare that the text of the printed version of my master thesis is identical with the text of the electronic version uploaded into the IS/STAG.

I acknowledge that the Technical University of Liberec will make my master thesis public in accordance with paragraph 47b of Act No. 111/1998 Coll., on Higher Education Institutions and on Amendment to Other Acts (the Higher Education Act), as amended.

I am aware of the consequences which may under the Higher Education Act result from a breach of this declaration.

April 29, 2022 Bc. Linda Phanová

Annotation

The author examines the use of lean management in a specific economic entity and makes ideas for improvement in certain areas of the company's internal system. The theoretical foundations of lean management are the subject of the research portion of the diploma thesis. The application section of the diploma thesis is concerned with the presentation of the company and the selected logistical section on which this thesis is focused. The internal system is then defined. This diploma thesis suggests an upgrade in handling technology characteristics in the automotive industry. The proposal will adopt the Li-ion battery solution for efficient and effective improvement in the field of logistics. The analysis and proposal for improvement of logistics in the department of axle production have been implemented in ŠKODA AUTO a.s. in Mladá Boleslav. Based on the identified and interpreted results from the analysis, it is pointed out critical areas in the company's internal system. Finally, they are introduced and economically evaluated recommendations to address shortcomings in the company’s area of lean logistics.

Keywords

Lean logistics, wasting in movement processes, lean management methods, handling technology, Li-ion battery, lead-acid battery

Anotace

Autor zkoumá využití štíhlého managementu u konkrétního ekonomického subjektu a přináší náměty na zlepšení v určitých oblastech interního systému společnosti. Teoretické základy štíhlého managementu jsou předmětem výzkumné části diplomové práce. Aplikační část diplomové práce se zabývá prezentací firmy a vybraného logistického úseku, na který je tato práce zaměřena. Poté je definován interní systém. Tato diplomová práce navrhuje vylepšení charakteristik manipulační techniky v automobilovém průmyslu. Návrh převezme řešení Li-ion baterie pro efektivní zlepšení v oblasti logistiky. Analýza a návrh na zlepšení úseku logistiky ve výrobě náprav byly realizovány ve ŠKODA AUTO a.s. v Mladé Boleslavi. Na základě zjištěných a interpretovaných výsledků analýzy je poukázáno na kritické oblasti interního systému společnosti. Nakonec jsou představena a ekonomicky vyhodnocena doporučení k řešení nedostatků v oblasti štíhlé logistiky společnosti.

Klíčová slova

Štíhlá logistika, plýtvání v pohybových procesech, metody štíhlého managementu, manipulační technika, Li-ion baterie, olověná baterie

Acknowledgment

I would like to thank my thesis supervisor, Mrs. Ing. Eva Štichhauerová, Ph.D. for her valuable and insightful comments and recommendations in creating this master thesis. My gratitude goes to a number of ŠKODA Auto a.s. personnel, including my consultant, Mr. Bc. Tomáš Dvořák, and other logistics workers in axle production for their constructive recommendations and the provision of internal information resources. Last but not least, I would want to express my sincere gratitude to my father and brother for their patience and support, which I truly appreciate.

„Công cha như núi Thái Sơn. Hy sinh tất cả cho con nên người"

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AGV – Automatic Guided Vehicles

AI – Artificial Intelligence

CPS – Cyber-Physical Systems

CZK – Czech koruna

ca. – circa

EDI – Electronic Data Interchange

DSG – Speed direct-shift gearbox

GPS – Global Positioning Systems

IoT – Internet of Things

JIS – Just in sequence

JIT – Just in time

KNR – Kennnummer (vehicle identification number)

Li-ion batteries – Lithium-ion batteries

MEB – Modular electric drive matrix (battery for electric vehicles)

MRP – Materials Requirement Planning

NVA – non value added

PDA – Personal Digital Assistant

PHEV – Plug-in hybrid electric vehicles

PK – Component Production

PKL – Concern of Component Logistics/Management

ŠKODA – ŠKODA Auto a.s.

TPM – Total Productive Maintenance

TPS – Toyota Production System

TQC – Totally Controlled Quality

TQSC – Totally Quick Settings Change

VA – value added

VSM – Value Stream Map

WIP – Work in Process/ Progress

WMS – Warehouse Management Systems

Introduction

Manufacturing companies assess and seek ways to improve their current production and logistical operations on a daily basis. It is a continuous process of improving not just the product's quality, but also internal business procedures. It can actively contribute to process improvement and the achievement of organizational objectives. The waste conceals factors that have a detrimental influence on organizational goals. Every organization that wishes to flourish should strive to reduce or eliminate waste to make the process more suitable. For their application in mass manufacturing, lean processes and technologies are well-known. These are mostly in the car industry. Automation and digitization are sections that have an interfering factor with all operations, particularly with the logistics department. Due to that situation, it is putting more pressure on consumer expectations and energy savings. Businesses that provide logistic services are now a days more and more competitive. Due to fierce competition between the competitors. Companies have to provide the services with the most cutting-edge technology strategies in their operations. With the current technology and strategies, there is a high rate of repetitive activities and transactions in logistics operations. As a result, incorporating these technologies into logistical procedures is nearly essential. Logistics is an ideal industry for using sophisticated automation technologies to improve efficiency, save energy, and reduce labour costs. These technologies provide significant advantages such as: cost reductions, flexibility, time savings, and increased safety of the employees will be realized with the use of the technologies and procedures described in the diploma thesis.

The thesis "Lean logistics in axle production" aims to identify critical points in the selected production process of ŠKODA, design, with the help of lean tools, possible improvements to the selected company's efficient logistics and production process, and eliminate these critical points, and economically evaluate recommended changes. This is preceded by an analysis of the current situation in ŠKODA AUTO a.s.

The thesis is divided into three main parts. The introductory part is devoted to lean management where the terminology of lean logistics is explained and described as well lean methods and tools. The second part will be the firm introduction and characterization with the focus on department of material management. In addition, the current state of the company ŠKODA AUTO a.s. will be analysed and the selected production process and measures will be proposed to eliminate the identified shortcomings. It is necessary to analyse the results and set objectives for their eventual outputs. The final chapter summarizes and presents the author's solutions and suggestions for which it can quantify the financial advantage and will be able to include in the evaluation.

1 Lean concept

Lean is about speeding up the supply chain to save working capital and eliminating wasteful resources utilized to provide a product or service to boost profitability. A quick supply chain necessitates an agile company that can not only predict changes faster than the competition but also pro-actively drives changes to gain a competitive advantage (Achahchah 2018).

The first principle of Lean was described in 1988 by Taiichi Ohno, where he explained the creation of a lean flow. According to Taiichi Ohno, we are looking at the timeline from when the consumer places an order to when we collect the money. Moreover, we are shortening the time frame by eliminating non-value-added waste (Liker & Meier 2006).

Womack and Jones were other thinkers who brought the term "Lean Management" into the world. In the book, *The Machinery That Changed the World (*1990) and then later in the expanded book *Lean Thinking (1996)* was suggested the five-step approaches of lean (Svozilová 2011). These books describe lean concepts in these five main points:

1. **Value** deals with what is essential for the effective functioning of the process of the customers, which should be expressed in terms of quality, service, and costs.
2. **Mapping the value stream** has the ability to distinguish between value-added and non-value-added activities which contribute to the delivery of services to the customer.
3. **Flow** keeps the workflow on the move and eliminates waste and the potential creation of waiting.
4. **Demand/pull** prevents from creating or ordering more products than the customer actively requires.
5. **Striving for perfection** completes the elimination of wastage so that only value-added activities remain (Achahchah 2018; Svozilová 2011).

Figure 1 depicts a typical division of conventional enterprises' value-added and non-value-added operations. Non-value-added activities such as waiting occupy the bulk of the overall lead-time from order to delivery. Non-value-added activities are described as work that is expensive and that the client is unwilling to pay for. Those operations do not add value to the service requested by the consumer. Only a tiny percentage of the time, 1–10%, is utilized to create value, such as transferring knowledge into the service the consumer desires. Traditional businesses attempt to accelerate value-added tasks but lowering this time by, say, 50%. This leads to results in much fewer advantages when compared to reducing non-value-added activities by the same proportion. The primary principle behind Lean is to concentrate on decreasing non-value-added operations since the potential for improvement is considerably greater. There may be operations that do not add value to the customer (for instance, trade compliance), but these cannot be avoided and must be carried out in order to comply with rules and laws. Lead times and inventory levels are two interconnected metrics for measuring value stream performance. The shorter the lead time, the less inventory is required to meet the client's demand (Achahchah 2018).

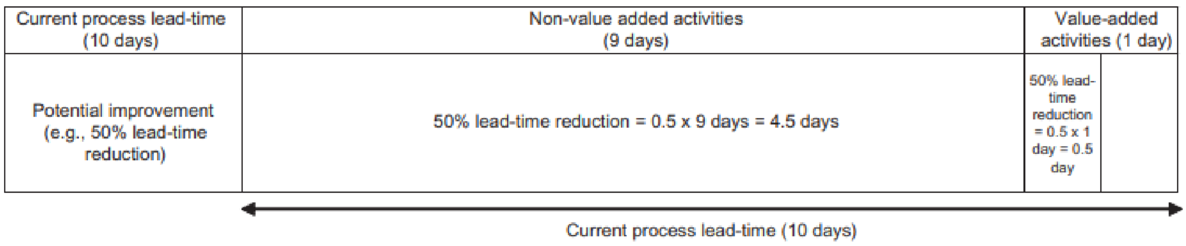


Figure 1: Value and non-value-added activities

Source**:** Achahchah (2018, p. 6)

1.1 Usage of Lean in praxis

A company's real success stems from an improvement process for discovering waste, analysing the core cause, and implementing effective remedies. Developing a lean system is analogous to putting money down for retirement. In order to reap the benefits in the long run, effort and sacrifice must be done in the short term. The implementation process will necessitate the sacrifice of time and money today in exchange for possible future rewards. The key to success, like with investing, is to start early and make consistent contributions (Liker & Meier 2006).

Lean methodology is used where we aim to increase process efficiency and decrease operating costs, which are reflected, for example, in the reduction of stocks, the reduction of production space, or the savings in labour spent on particular output. It is sought for in situations where processes must be simplified and straightened, and where the time between the input of a product and the transfer of its outputs to other processes must be reduced. Another important reason to use lean is to split process activities into those that add value to the product and those that do not have a direct link to the value that is progressively developed, or do not contribute to its production (Bradley 2012).

Regarding Svozilová (2011), to use the lean methodology, the company should use the following assumptions for its own analysis.

- Waste occurs in many different forms throughout the process.
- The speed at which the change is made in the operating process is crucial.
- Processes must be kept moving.
- Process changes must be methodical, and they must be supported and facilitated by a balanced complex of partial changes that influence all linked areas, including personnel, process systems, and technology.

In practice, lean is applied especially when:

- optimal market conditions require increased process efficiency or shorter order cycles;
- competitive forces are quite challenging, particularly in terms of pricing and service quality;
- customers demand reduced pricing;
- the organization seeks to minimize inventory;
- the headquarters are expecting higher returns on capital;
- the enterprise sees a method to boost market potential through improved quality products (Svozilová 2011).

2 Logistics

Logistics is defined according to CSCMP (Council of Supply Chain Management Professionals) as a part of supply chain management, which takes part in planning, implementing, and efficiently and effectively managing the flow of products, services, and related information from the point of origin to the point of consumption and storage of goods to meet end-customer requirements. Activities in logistics include transportation, fleet management, warehousing, material handling, order fulfilment, design of logistics network, inventory management, supply and demand planning, and logistics services provider management. Logistics tasks also include sourcing and purchasing, production planning and scheduling, packaging and assembly, and customer support to varying degrees. It is involved in all levels of strategic, operational, and tactical planning and implementation. Logistics management is a coordinating and optimizing role that integrates all logistical processes with other areas like marketing, manufacturing, sales, finance, and information technology (Gros et al. 2016). In the lean world, logistics management is controlling the flow of goods to reduce stocking, inventory, and cycle time – anything that wastes the company´s resources (Sayer, 2012).

According to Dolan (2018), the priority goals are divided into two groups, where the following objectives are among the logistics top priorities.

- **External** aims on the satisfaction of customers, this contributes to maintaining or further expanding the range of services provided such as increasing sales, shortening delivery times, improving the reliability and completeness of supplies, and improving the flexibility of logistics services.
- **Performance** ensures that the required amount of material and goods will be in the right number, in the right place, at the right time with the requested quality.

Secondary goals include internal and economical objectives:

- **Internal objective** focuses on reducing costs while meeting the compliance of external objectives, such as costs for stocks, transportation, handling and storage, production, and management.

- **Economic objective** aims at providing services at adequate costs, which are minimal due to the level of services. The costs then correspond to the price the customer is willing to pay for the higher quality (Dolan 2018).

2.1 Inbound and Outbound logistics

Inbound logistics is the process of bringing resources and other commodities into a business. This procedure covers the steps required to order, receive, store, transport, and manage incoming products. Considering being a manufacturer of automobiles, inbound logistics for manufacturing would include acquiring raw material inputs, storing the materials in preparation for and throughout the assembly process, mode of transportation selection, and managing the flow of finished cars that leave the facility (Jenkins 2020).

Outbound logistics is concerned with the supply side of the supply-demand relationship. The procedure includes storing and transporting items to the client or end-user. Order fulfilment, packaging, shipping, delivery, and customer assistance connected to delivery are among the phases. Returning to the auto manufacturing example, the wholesalers and dealers are the parties involved in the supply chain's outbound logistics. Factory operations would be responsible for ensuring that the correct amount of requested goods gets to the dealer on time. What happens within each of the networks has an impact on the plant although it is often invisible to managers beyond the first tier. Allowing each plant to learn more about its suppliers and consumers is a declared goal of supply chain management, but it is not yet commonly employed (CFI Education, 2021; Jenkins 2020). The whole process of inbound and outbound logistics is illustrated in Figure 2.

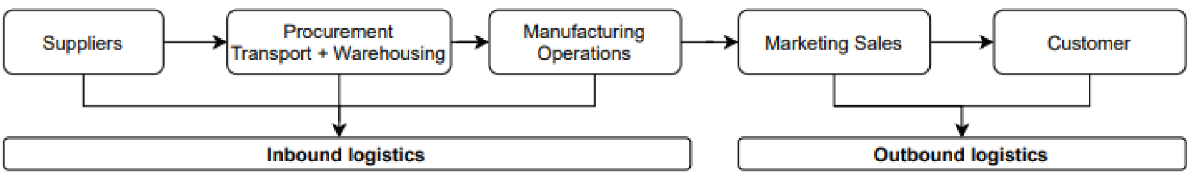


Figure 2: Inbound and Outbound Logistics Activities

Source: Paksoy (2021, p. 17)

Another important barrier is the one that exists between the plant and the rest of the world, which is often manifested in the form of docks for receiving and shipping. **Dock-to-dock logistics** is another term for in-plant logistics. Aside from the obvious variations in distances, quantities, and vehicles, in-plant logistics differ from in-bound, logistics of obtaining parts from suppliers and out-bound logistics of delivering finished items in the manner in which it is managed. One entity is in charge of in-plant logistics. In- and out-bound logistics, on the other hand, are governed by the interplay of several separate economic agents, such as multiple tiers of supplies and distributors, trucking firms, railways, and air and sea freight businesses, each of which makes its own decisions (Baudin 2004).

A close examination of the transportation system within the plant frequently reveals that production is dissatisfied with its performance, that it is not as safe around people as it could be, that it uses the wrong vehicles or methods for specific needs, and that it consumes more resources than it should. In-plant transportation differs from inbound and outbound transportation in that the largest gains are obtained by eliminating trips rather than cutting distances (Baudin 2004). In the following chapter, the vehicles being commonly used for dock-to-dock logistics in the selected company ŠKODA Auto a.s. (hereinafter ŠKODA) are listed and described.

2.1.1 Types of vehicles

In the late 1940s, the strong development of today's well-known manufacturers of material handling equipment, such as Jungheinrich, BT, Toyota, Hyster, Linde, and Yale, began. In 1946, Hyster Company established its first plant in Danville, Illinois (USA) dedicated solely to the mass manufacture of lift trucks. BT developed the first-hand pallet truck in 1948. Jungheinrich manufactured the first reach truck, "Retrak," in 1956, as a milestone defining moment of space-saving storage. At the same time, they began manufacturing their own electric motors. Hyster launched its first plant outside the United States in Nijmegen, the Netherlands, in 1952. The first machines assembled there were the Hyster 40" and Karry Kranes. Linde produced the first hydrostatically driven vehicle, the so-called Hydrocar, in 1955. Toyota created the first counterbalanced forklift truck in 1956. Today, all material handling manufacturing companies are committed to the long-term growth and sustainable development of their manufacturing plants and products (Shevtshenko et. al. 2012).

Material handling product modularity is the idea underlying more sustainable design. As a result, the new reverse logistics framework for more sustainable material handling equipment includes a technical condition control phase. Returned equipment is often used product, and the overall condition of the parts should be evaluated before they are reused in the reconfiguration process. The redesigned equipment should be dependable and meet consumer requirements. The author summarizes the distinctions between more sustainable and conventional design for material handling equipment in Table 1.

Table 1: Differences between conventional and sustainable design of material handling equipment

Conventional design	**Sustainable design**
Product design is fixed	Product design is dynamic in the frames of given product portfolio
Product disposed when customer requirements are changed	Product reconfigured when customer requirements are changed
Product features should be selected at the moment of the product purchase	New features can be added to the product when required
Product life cycle is fixed	Product life cycle has the potential to get increased

Source: Shevtshenko et. al. (2012)

The most extensive category of handling equipment nowadays (Figure 3) is composed of numerous motorized handling trucks designed for horizontal and vertical movement. The propulsion unit is either petrol, diesel, or gas, and for lower load capacities, electric motors powered by rechargeable batteries carried in the truck are employed. They enable transportation between warehouse zones (Gros et al. 2016).

In ŠKODA, especially in the Hall M1 (axle production) are being used handling technologies from Jugheinrich and Still company. There are in total 34 handling pieces of equipment, of which 7 are tuggers, 21 forklifts, 4 reach trucks, and 2 Automatic Guided Vehicles from the company CEIT.

Figure 3: Handling equipment overview

Source: Dvořák (2022)

Forklifts are the most common in-plant devices used for transportation. Although forklifts are versatile and strong, they are not without drawbacks. They cost tens of thousands of dollars, can only be operated by properly trained drivers, are a safety concern that must be confined to run in designated locations, and are only suitable for transferring pallet-sized goods, not smaller quantities (Baudin 2004).

Reach Trucks with a lifting device installed on the side are used for handling long products or reaching high for objects. The side installation is also utilized for narrow aisle handling. It boosts their agility when combined with a three-wheel chassis. Load capacity, lift height, travel speed, lift speed, inclination, and traction are the fundamental performance criteria of the trucks (Gros et al. 2016).

Neither the forklift nor the individual pushcart can deliver thousands of items in box amounts at multiple locations every half hour, as is frequently required in the automobile sector. The idea is to connect carts to a railway and pull them along designated routes with a tugging engine whose driver also loads and unloads the boxes along the way (Baudin 2004). The **tuggers** have a combined rotation of all four wheels, which reduces the turning radius of the entire lift. Even unsupervised lifts controlled by conductors located on the floor are employed in the supply of manufacturing lines. Their operation results in reduced operating expenses, particularly for personnel, as the lift replaces multiple conventional vehicles handled by the operator (Gros et al. 2016).

Automatic Guided Vehicles have been present since the 1980s. The use of AGVs is a common occurrence in flexible manufacturing systems that utilize transport robots in their production operations. AGVs' paths are limited to predetermined routes by implementing magnetic stripe navigation or guide wires, and they require the workplace to be restructured to operate efficiently (Paksoy 2021).

Manufacturers may now save data for a sustainably designed product, monitor product condition, and customer requirements, and facilitate product reconfiguration at the distribution site thanks to advances in information systems. The distributor can also notify the manufacturer of any modifications made to the product and replenish the accessories. As a result, a sustainable design that takes into account reverse logistics is ready to be implemented. The biggest issue for material handling equipment distributors is that consumers prefer to operate on long-term leasing agreements, which benefits large corporations. If appropriate warehouse equipment is ordered and a long-term leasing arrangement is formed, there are certain benefits. To begin with, no relationships with banks or other leasing businesses occur. The distributor rents directly to the companies. This implies the firm may return the old reach truck and order a new one after five years. The larger monthly payments offset the risk of taking out a bank loan. Distributors are facing the challenge of customer enterprises liquidating as a result of the unstable economic scenario. Paying a penalty and returning the reach truck is more beneficial for the consumer than cancelling the bank loan. The amount of returns is reduced when sustainable reach trucks are sold. A reach truck that has been developed sustainably has the potential to be reused. If a reach truck that has been developed for sustainability is returned, it may be simply altered to meet the needs of the new customer (Shevtshenko et. al. 2012)

2.1.2 Rechargeable batteries

When evaluating the energy supply alternatives for powering your LED signs, many site managers wonder which battery to use. The most frequent choices are lithium-ion batteries (hereinafter Li-ion batteries) or lead-acid batteries, both of which have advantages and disadvantages.

Lead-acid batteries are characterized by short-term high current consumption. The main advantages are well-managed production technology, relatively low price, and high performance. Lead-acid batteries with liquid electrolytes may be constructed as open and closed wet batteries. Traction batteries designed for deep discharge, which are much less subject to electrode wear, have long been employed for handling technology. They are used where batteries are regularly discharged and recharged – low or forklifts, golf carts, electric cars, etc.

Li-ion batteries are a type of rechargeable battery that is widely utilized in consumer electronics. It is ideal for portable devices because to its high energy density. This advantage may be leveraged extremely successfully in handling technology since batteries do not have a memory effect, do not need to be formatted, and have a self-discharge rate of roughly 5% (Simplelift 2019).

Although all batteries lose efficiency with time, Li-ion batteries often last many times longer than lead-acid batteries due to greater life cycle numbers, which reduces the frequency with which they must be changed. This saves money on battery disposal charges since batteries must be disposed of in line with recycling laws. Li-ion batteries are also more durable and will work better in a challenging environment. The **advantages and disadvantages** of the batteries are being compared in Figure 4.

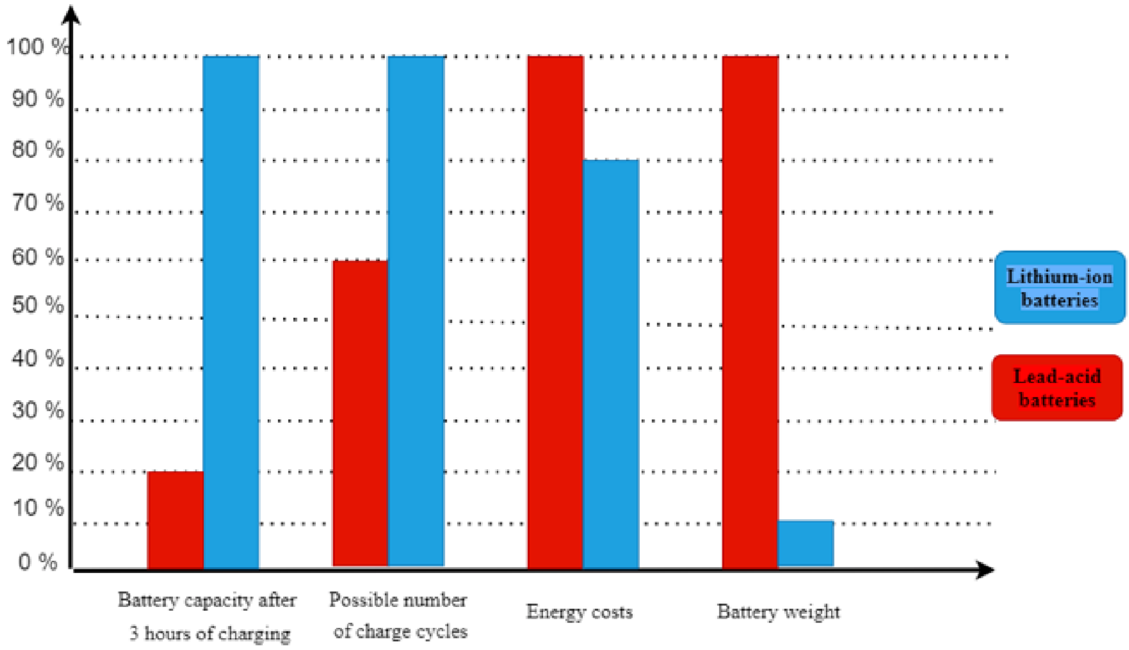


Figure 4: Comparison of the Li-ion batteries and lead-acid batteries usage

Source: Simplelift (2019)

When comparing Li-ion vs lead-acid batteries, **efficiency** is an important factor to examine since it refers to the percentage of energy stored in the battery that can actually be utilised. Li-ion batteries are typically at least 95% efficient and both partial and rapid charging is acceptable, whereas lead-acid batteries give efficiencies of 75-80 % and fast or partial charges ruin the battery. A lead-acid battery requires more energy to recharge than it provides. The extra energy is used for gasification and internal acid mixing. This process heats the battery and evaporates the water inside, necessitating the addition of distilled (demineralised) water to the battery. This is significant because it allows the battery to charge faster and has a higher effective battery capacity, which refers to how much energy the battery can store. Effective battery capacity indicates that a Li-ion battery can store more energy than a lead-acid counterpart in the same physical space, allowing it to power signs for longer periods of time. The charging time of lead-acid batteries takes from 6 to 8 hours to reach up to 80% of its full capacity, whereas Li-ion batteries can be charged up to 80% capacity in 1 to 2 hours (depending on the power output of the charger). It will take another 2 to 3 hours to complete the remaining 20%. As a result, a Li-ion battery may be fully charged in 3 to 5 hours (Flash Battery 2017).

Li-ion batteries also have a considerably superior **discharge curve**, with the battery voltage dropping very little until nearly totally discharged, whereas lead-acid batteries have large voltage drops throughout the discharge rate (Pilot group, 2022). With just two years of satisfactory service (when discharged at half of its full capacity), the **life span** is exceptionally short, especially for a century-old technology. If your lead-acid battery is fully discharged at each cycle (80% or more), it will only last one year. Li-ion batteries, on the other hand, have extended their life span during the previous 5 years, and manufacturers are now providing guarantees of up to 10 years (70% of initial capacity) (Metaye 2022).

2.1.3 Measuring transportation system performance

Distance might range from a few kilometres to thousands of kilometres in inbound and outbound logistics, and it is, of course, an important factor. Inside the plant, however, whether you move pieces 1 meter, or 100 meters makes a little effect. As Baudin (2004) has stated other acts must take place during inbound logistics regardless of distance.

- The bare minimum of transportation must be accumulated at the point of origin.
- The parts must be prepped for shipping, which may include putting them in bins and palletizing the bins.
- A vehicle, such as a forklift with a driver, must arrive and pick up the parts.
- When the components arrive at their destination, they must be prepped for manufacturing, which includes removing them from pallets and bins and perhaps placing them on lineside shelves (Baudin 2004).

The nature of the work determines the variation in individual activities. Order transmission is highly reliable when using the electronic transfer (EDI) or Internet communication and more erratic when using the telephone or regular mail. Regardless of the level of technology deployed, an operational variance will occur as a result of daily changes in workload and the resolution of unexpected events. The logistics performance cycle is the fundamental unit of supply chain planning and control. In all operational domains, the primary goal of logistics is to decrease performance cycle uncertainty (Bowersox et al. 2013). Cutting the distance between two lines of distribution in half has no effect; however, merging the two lines and removing the transit phase does.

The volume of traffic between destinations is, of course, the first step in evaluating in-plant transportation. If a forklift transports one pallet from point X to point Y every 20 minutes, it's probably a good idea to find a better solution, which might include modifying the plant layout to put points X and Y closer together and removing the transportation phase. However, if that route is only used by one box once a month, it is not a potential target for improvement. After identifying a highly trafficked route, the next step is to track a shipment and see what happens to it. One method is to count the number of times a part is touched as an individual unit, in a tote, and on a pallet during the journey (Baudin 2004).

2.2 Logistics 4.0

During the 1990s and 2000s, supply chains and logistics faced significant and fast changes. As economies and markets have grown more international, the purchase and distribution of commodities have been impacted. As a result of the developments in the logistics industry, new information technologies such as EDI, the Internet, and GPS via satellites evolved. Logistics 4.0 is a collective term for technologies and concepts of value chain organization. Many developing technologies play an important role in Logistics 4.0. This notion includes the collective usage of barcodes, radio frequency identification technology (RFID), sensors, GPS, and other modern technologies for information processing and network communication. A future factory is envisioned as a Cyber-Physical Systems (CPS) that links machines and humans. Automated logistics operations and efficient transportation procedures improve service levels and customer satisfaction while lowering overall costs and natural resource use. The essential technological applications for Logistics 4.0 are Warehouse Management Systems (WMS) and the Internet of Things (IoT) (Paksoy et al. 2021).

The introduction of smart technologies, as well as their deployment and integration into WMSs, results in a significant transformation of warehouse activities. According to Meyerson (2012), WMS can help to decrease waste in a variety of ways. The **intelligent WMSs** can track the position and expected arrival time of transporters via CPS. As a result, intelligent WMSs will be able to maximize JIT and JIS delivery by determining and preparing the appropriate docking location. At the same time, the RFID sensors will provide delivery data (such as quantity, price, and size) to the whole supply chain. The necessary material handling equipment will be asked to transfer the arriving products, and available storage space will be allotted instantly by the WMSs depending on the circumstances of the delivery (Kampf et al. 2017). The systems are implemented to reduce the volume of material on the assembly line, save money, decrease mistakes, and boost productivity. This saves space and prevents possible downtime.

The internet is a new trend of communication. It has the ability to connect physical objects and develop smarted services for the environment. The **Internet of Things** enables businesses to track their goods in real-time at each stage of the logistics process and manage their logistics architecture. While the flow of products is being tracked, a company may evaluate the data collected at each stage of the logistics process and share the information with all parties involved. The utilization of real-time data in forecasting enables businesses to recognize future patterns and the likelihood of unforeseen events. As a result, preventative actions or policies can be put in place ahead of time. Businesses gain a competitive advantage by becoming more responsive to the market (Kampf et al. 2017).

A **quick response (QR)** system was designed and deployed in the sphere of production and distribution to leverage the attained impacts in a larger framework. QR is a system focused on the chain of consumer goods from production through wholesale to the retail network (compared to the customer-supplier relationship, there is a broader focus). Working partnerships – information on sales, orders, and inventory that is shared by individual nodes in the chain – are required. It is required to implement automated identification – bar codes, QR codes - so that individual product sales to consumers can be tracked and the information resulting from this may be distributed in real-time to all links in the chain (Dolan 2018). The initial problems associated with highly expensive sensors have been eliminated by digital cameras, which can read these codes optically up to a distance of 15 m and, more interesting, to capture information at different angles, which was not possible with conventional sensors (Gros et al. 2016). An example of the 2D codes is shown in Figure 5.

Figure 5: 2D codes (left: Semacode, right: QR code)

Source: Toyota material handling cz (2021, p. 9)

The essence of the most widespread optical system is the well-known **EAN barcodes** from retail stores, where they streamline the process of payments at cash registers. However, the main area of application of this technology is in monitoring the flows of goods throughout the supply system. Labels are used to identify items and handling units, on which numerical data is encoded with a suitable combination of vertical lines and spaces. An example of a barcode is shown in Figure 6. They enable quick acquisition of basic information from product identification, place of origin, production delivery number, series, production line, product in handling unit, a number of packages, production and packaging dates, expiration timeframes, durability, and others (Gros et al. 2016).

(01)08591234560016(15)181224(10)ABC12345

Figure 6: Identification label for the handling unit (Bar code)

Source: EPRIN (2020)

Since integrating **Artificial Intelligence** (AI) into a company´s business model, several warehouse and shipping organizations have been taking advantage of information technology, robotics, and automated systems as a result of the creation of the Smart Logistics concept. The fast development of AI and robotics technology has resulted in ground-breaking solutions for the logistics business, such as autonomous warehouses and delivery drones. As a result of using intelligent warehousing and delivery services, businesses drastically reduced shipment times and increased customer service quality. Unlike the manufacturing business, the logistics sector must deal with adaptation issues caused by a wide range of orders from several customers. Because each order in the delivery sector is different in terms of sorting, packaging, and delivering, technical devices and equipment should be provided with intelligent features. This technology enables businesses to focus on personalization by taking each client's needs into consideration, as well as enhancing customer service by providing the appropriate item in the right place at the right time (Paksoy et al. 2021).

3 Selected lean tools for streamlining the logistics system

Logistics technologies are a set of approaches used to make the logistics system operate at the lowest feasible cost while meeting customer expectations. The selection and structure of individual operations using appropriate methodologies and management procedures are to operate optimally with regards to the lowest possible cost. By selecting the appropriate logistics technology, the organization may accomplish business and trade development while minimizing expenses. The following approaches can be classified as logistics technology.

3.1 The Eight Wastes

Non-added-value are defined as waste ("Muda" in Japanese), an uneven workload ("mura"), and labour that places a burden on team members or procedures ("muri"). Seasonality, unrealistic deadlines, and end-of-month rush orders for "making the month" are all examples of "mura." Information overload, firefighting, stress, and burnouts are all examples of "muri" (Achahchah 2018).

"Muda" generates the most wastes, which is classified regarding Liker & Meier (2016) into seven categories, see below.

- **Transportation/Movement** moves (semi-)finished items to or from storage units, and other wasteful motions such as temporarily locating, stocking, stacking, moving material or people. The concepts of layout and the visualization of the workplace plays an important role.
- **Inventories** include *raw materials* ("bought in large quantities due to a good price"), work-in-process (WIP) (the transformation process has been started or is awaiting the next process and is still not complete), *finished goods* ("safety stock" for demand fluctuations or waiting to be sold, saleable products), *spare parts, and other repair material and tools* (extra parts for "just in case"), as well as the *storage* of too much information not needed.

- **Motion** is unnecessary walking, looking for tools, excessive reaching and bending, and material placed too far.
- **Waiting** is a waste of time by spending it on waiting on material, supplies, information, and people to provide input for the upcoming steps.
- **Overproduction** is classified as processing products or ordering before it is requested, this later results in an excess of inventory.
- **Overprocessing** means wasting time and effort by processing material or information that does not add value to the customer. This can also mean utilizing equipment that is more expensive, complex, or precise than is required to do the task.
- **Defects** is the term "waste of faults" in manufacturing refers to materials that have been repaired, reworked, or scrapped. The cost of a defect increases as it progresses, as the company may need to rework it into the system, scrap it and start all over again, or, in the worst-case scenario, have it returned from the customer, which can entail safety and liability issues, as seen in the Tylenol and Toyota recalls.
- **Behavioural Waste (or Underutilized Employees)** is addressed as not leveraging employees' knowledge, skills, and ideas, nor offering special training (Liker & Meier 2016, Meyerson 2012).

The aim is to identify and remove the seven categories of waste outlined above. These are the strategies for doing so and shortening lead times:

- "Simplify,
- Streamline,
- Standardize,
- Use visual systems,
- Mistake- proof processes and product designs,
- Synchronize,
- Collocate,
- Reduce changeover time" (Bradley, 2012).

3.2 5S: Workplace Organization and Standardization

The 5S tool creates a well-organized workspace with visible controls, a better layout, and more order. Fewer accidents, greater productivity, decreased searching time, reduced contamination, visible workplace management, and a basis for all other development initiatives arise from a clean, organized, ordered, safe, efficient, and enjoyable workplace. Lean is frequently adopted initially in the supply chain and logistics function, particularly in terms of warehouse operations. The main reasons are that it is a reliable basis for future advancements and that it is simple and easy to understand and to apply. The 5S process may begin once the team has chosen an area and conducted an initial workplace scan (Myerson 2012).

- **Sort** (Japanese *Seiri*): excludes all actions, tools or components that is not necessary in that area (just like the saying says 'When in doubt, toss it out').
- **Set in order** (*Seiton*): during this phase, careful consideration should be given to the layout of the area as well as the flow of materials and information. The individual process needs are saved and are easily accessible in order to ensure a smooth and efficient workflow.
- **Shine** (*Seiso*): everything is cleaned and, in some cases, painted at this step. One of the main goals of cleaning is to keep all equipment in good working order so that it may be utilized at any time.
- **Standardize** (*Seiso*): establishing a method for carrying out tasks and processes in a consistent manner to ensure repeatability of units.
- **Sustain** (*Shitsuke*): refers to developing a long-term habit of following procedures, guidelines, and rules set in the previous four steps (Svozilová 2011, Myerson 2012).

3.3 JIT and JIS

JIT stands for just-in-time delivery of goods in the needed quantities and conditions at the appropriate time and location as well securing and keeping to a long-term plan and synchronized deliveries and production. This method is based on the pull principle (see Figure 7) in which just what is essential and demanded by the market and the customer is produced (Jurová et al.

2013). Smaller volumes arrive more frequently and on a more consistent timetable with a geographically appropriate distribution of sites production and consumption (Achahchah 2018).

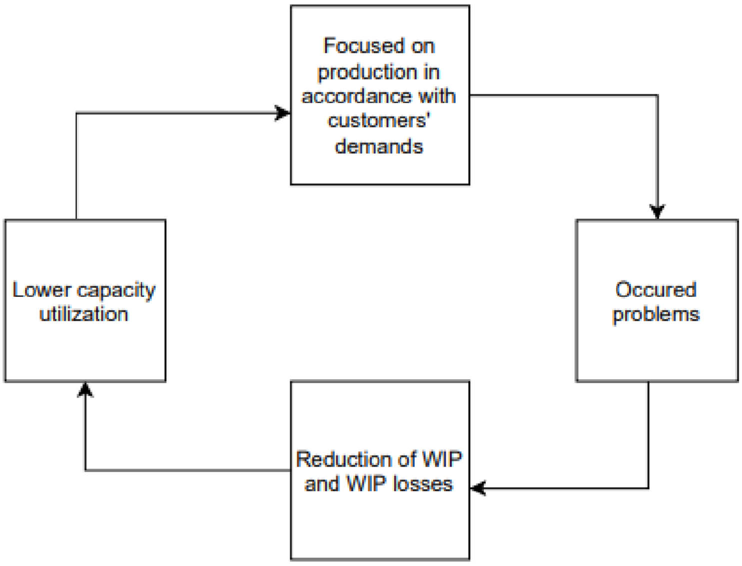


Figure 7: Schematic course of processes in pull system strategy

Source: Kampf et al. (2017, p. 199)

Typically, the sourcing or purchasing manager strives to lower the company's material expenses to the greatest extent feasible. This leads to higher purchases. The same is true for the logistics manager, who prioritizes low prices and reliability in the transportation and distribution network. When operations are JIT-based, however, it is still necessary to focus on cost and reliability, but new dimensions, such as flexibility and agility, are now added to satisfy quickly changing customer shorter-term demand. In a JIT environment, the aim is on lowering total cost. The principles of the JIT system are outlined in Figure 8. Other factors must be considered, such as shipping, handling, and storage expenses, as well as new sorts of supplier relationships. By concentrating on reduced total cost, it is possible to partially offset the higher transportation and handling costs of smaller loads while also benefiting from cheaper storage and overall carrying costs. A flawless information system and the relationship between the partners (suppliers and buyer) is required because the price and the quality can be on a higher level (Meyerson 2012).

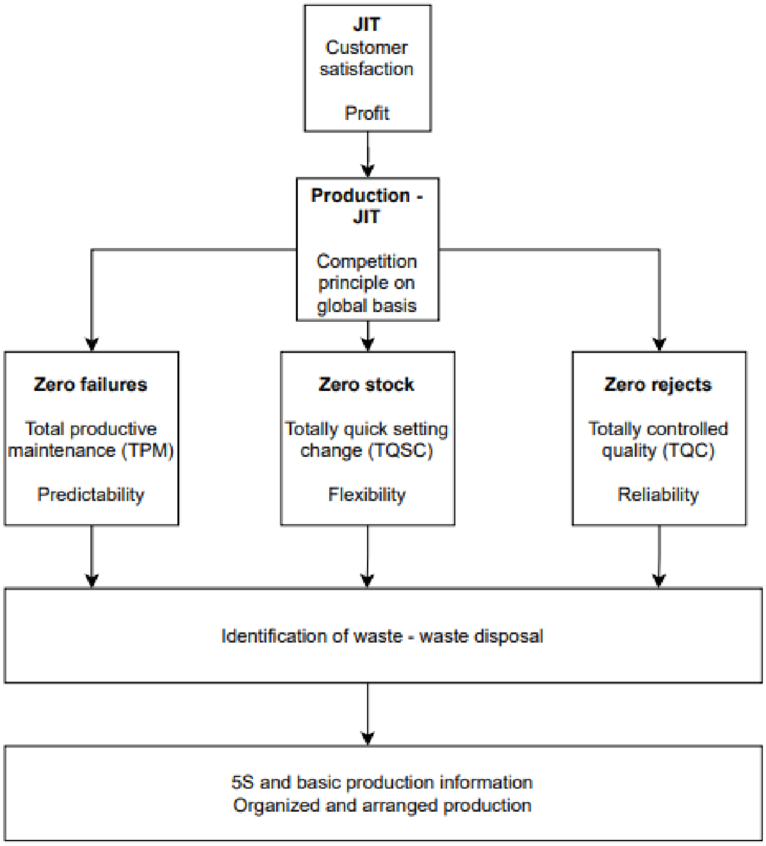


Figure 8: Concept of JIT system

Source: Kampf et al. (2017, p. 172)

It is more of a management system based on self-regulation. A continuous product quality management (TQM – Total Quality Management) is an essential component of this system, which ensures continuous manufacturing quality by testing, preventing, and correcting deviations as soon as they occur (Kampf et al. 2017). This method reduces storage costs (by lowering storage levels), but it does not eliminate them completely. There are always a minimum insurance reserves (for example, in ŠKODA are reserves kept in the tanks at the assembly line). It consists in satisfying the need for a certain material during production or after a certain final product in the distribution piece by delivering it just in time (Dolan 2018).

The **just-in-sequence (JIS)** supply strategy is based on the just-in-time concept, according to the literature. The JIT supply is common for engineer-to-order items, when the product specifications entail unique engineering design or extensive modification (Bányai et al. 2019).

The supplier is synchronized with the assembly line, and they sort the parts into bins in a precise order, facilitating the task of the production operators and ensuring that components are withdrawn in the correct production sequence according to schedule (make-to-order) (Fathi et al. 2020). The JIS strategy attempts to achieve short order lead times and on-time customer deliveries while maintaining minimal inventories and a fast throughput. This strategy supports mass-customized and cost-effective way of production of goods, resulting in possible reduction in handling costs. JIS also has vulnerable spots, where integrated supplier-buyer relationships can increase rework when unreliable processes are prevalent (Tornese et al. 2017).

3.4 Visualization tools

Lean layout is a process in which waste is minimized, products continue to flow instead of sitting in a line, aisle, or other location. The layout of a facility is determined in this regard. Because travel time is so important for productivity in a warehouse, a well-designed layout is crucial. The objective is to have your fast-moving items closer to shipment and lower down, while your slower-moving items are further away and higher up (a practice known as 'velocity slotting'). It is also critical to have tools, equipment, supplies, and packing materials readily available and near at hand (Myerson 2012).

A good layout:

- maximizes the use of space, equipment, and personnel;
- improves the flow of information, goods, or people;
- improves the moral of the employee;
- improves the interface of the customer;
- shows flexibility.

A **spaghetti diagram** is a visual depiction of a process that uses a continuous flow line to trace the passage of an item or activity. The continuous flow line, as a process analysis tool, helps process teams to find redundancies in the workflow and possibilities to expedite process flow. Wastes such as waiting, movement, and processing (described in chapter 3.1) require more detailed analysis, using movement charts. Congestion and delays are common in regions where many paths intersect. Because it is deemed "unnecessary motion," waiting is one of the eight wastes of lean. The spaghetti diagram helps to highlight key crossing points like these that could otherwise go unnoticed (King & King 2015).

4 Warehousing

Taiichi Ohnos' list of wastes (Chapter 3.1) includes the word "inventory" prominently. As a result, when discussing inventory or warehouse management, numerous participants quickly state that because "inventory is waste," it should simply be disposed of (Ohno 2013). An analysis of a distribution operation conducted around 2006, as described in *Are Your Warehouse Operations Lean?* by Ken Gaunt, revealed that a typical order was only worked on 38% of its cycle time; 56% of the time orders were idle, and the remaining 6% involved employees dealing with problems such as waiting for equipment, computer issues, interruptions, and blocked aisles (Myerson 2012). In this chapter, the characteristics, function, and possible improvements of a warehouse will be described.

4.1 Types of warehouses

Storage technology refers to the collection of technical tools and storage units used to carry out storage activities in a warehouse. The layout of their static element, which is subsequently reinforced by an appropriate dynamic part, is the key criterion for the separation of storage technologies (Gros et al. 2016). Because the static and dynamic components of various technologies differ, the specific technologies are described separately in the following text.

The organization of activities must be such that the flow of goods is as fast as possible. For the location of finished product warehouses, it is according to Dolan (2018) necessary to determine:

- number of storage stages – a vertical structure;
- number of warehouses in each stage – horizontal structure.

We differentiate four types of warehouses in the vertical structure.

- **Operating warehouses** or also warehouses of finished products. These warehouses are located within the plant and store only goods that have been produced on-site.
- **Central warehouses** are more efficient than operational warehouses. They always have a full selection of items and are frequently restricted in quantity. When there are

subordinate storage stages, it is the master function of the central warehouse to replenish supplies based on their needs. It is being prepared here for dispatch items for the customer in the specified amount.

- **Regional warehouses** store emergency supplies for the demands of a certain region's sales market, which has a significant number of places of sale. Only parts of are stored here overall range, considering the specific requirements of the region.
- **Dispatch (sales) warehouses**, which are at the bottom of the warehouse hierarchy. It is mostly used for selecting and transporting items for local consumers. Products having a high sales volume are kept here (Dolan 2018).

The single-deep pallet racking system, with a pallet as the handling unit, is the most common type of rack seen in buildings (and sometimes in open spaces – adjustable pallet racks) (Gros et al. 2016). It provides random access to slots, which means that any pallet may be collected without first moving anything out of the way. All levels are reachable with forklifts, narrow-aisle vehicles, or order pickers; however, the bottom level is more easily accessible, with pallet jacks retrieving full pallets or carts retrieving boxes off pallets (Baudin 2004).

Block stacking is a popular method. The key advantage of block stacking is that it requires no investment in racking and relies on the same forklifts that the factory utilizes for other tasks. It necessitates the stackability of pallets, which implies that the container walls must be strong enough to support the weight of numerous pallets. It is the polar opposite of flow racks, which rely on gravity to move pallets. Block stacking is the most labour-intensive approach since nothing moves until it is moved by a forklift. In ŠKODA pallet stacks are placed in FIFO (first in first out) lanes, and the retrieval from each stack is done as well on a FIFO basis. Because of these qualities, block-stacking is suited for high-volume, low-mix applications, with things supplied by the truckload every day. Because of its low setup costs, it is often utilized when a plant initially starts up, even if it does not meet long-term needs (Baudin 2004).

Another way to increase the use of warehouse space is to install **gravity racks.** They are used not only for storing goods on pallets, but it is also possible to store goods in various handling containers, including loose piece goods. Inclined racks are made up of numerous roller tracks of various constructions and the movement of goods on them is ensured by gravitational forces.

The rear, higher side is reserved for access to the shelves, after sliding in, the handling unit gradually moves to the front side, from where it is removed from storage. They are suitable for a limited range of goods. Goods can be taken from storage in the order in which they were stored. They are preferably used for equipping assembly lines, where high-turnover goods are usually stored in easily accessible crates. They can also be found on assembly lines. The disadvantages include the risk of failures of the roller tracks and the need to ensure their constant travel speed on the track in the event of high motility of the handling units. It is one of the most expensive shelves ever. They can achieve high utilization of storage space (Gros et al. 2016).

4.2 Warehouse operation of the company

Traditionally, a warehouse was thought to be a facility to hold or store inventory. However, in modern logistical systems, warehouse functionality is more accurately defined as the mixing and altering of inventory to fulfil the needs of customers (Bowersox 2013). The function of warehousing is to act as a link between the supplier and the end-user. Although there are several types, the flow of materials in a warehouse typically follows three processes: receiving, storage, and delivery to clients. The items supplied by trucks are received at unloading docks during the **receiving phase**. Picking products is being done from the **storage area** based on the customer's order. Choosing a replenishment strategy is based on inventory policy. During the stage by dispatch, orders are prepared and put onto vehicles to be **delivered to customers.** The process of warehouse functions is being described in Figure 9.

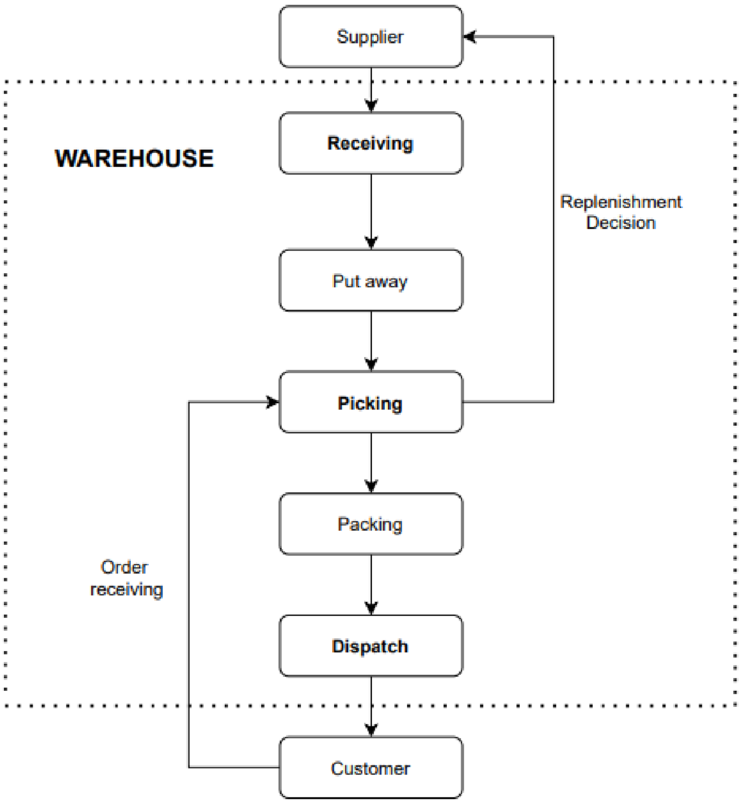


Figure 9: Warehouse functions

Source: Paksoy et al. (2021, p. 190)

Warehousing provides economic benefits by lowering total logistics costs. For example, if implementing a warehouse into a logistical system decreases overall transportation costs by a factor higher than the needed investment and operations expenses, the total cost will be reduced. When entire cost savings are achieved, the warehouse becomes economically justified. Consolidation and break-bulk, sorting, seasonal storage, and reverse logistics are the four main economic benefits regarding to Bowersox (2013).

4.3 Warehouse system automation

One of the most significant goals of a warehouse is to maximize flexibility. Information technology makes it easier to be flexible. Technology has changed practically every area of warehouse operations by introducing new and improved methods of storage and handling.

Flexibility is also required to adapt to ever-changing client demand in terms of product assortments, value-added services, and how shipments are routed and presented (Bowersox 2013).

Due to the general growing relevance of logistics and the strategic value of storage in logistics, companies are looking for ways to optimize their warehousing operations. Furthermore, volatile storage conditions make it difficult to undertake warehousing activities with the appropriate performance standards. These changing conditions include an increase in the quantity and variety of products in warehouses, an increase in value-added activities in warehouses, shorter product life cycles and faster delivery times, a high volume of product returns due to globalization, and an increasing need to complete all warehousing activities in less time and with minimal errors due to high business competition. As a consequence of all of the criteria, it has become obligatory to employ the most up-to-date technology in warehouses in order to decrease costs, optimize operations, and improve service quality. WMS, RFID, IoT (chapter 2.4), and AGVs (chapter 2.1.1), as well as drones, are the primary warehouse technologies and references (Paksoy et. al. 2021).

5 Introduction of the company ŠKODA

The following chapter of this diploma thesis is devoted to the characteristics of a selected economic entity, which was chosen by the author to demonstrate the practical application of lean logistics. First, a selected economic entity will be briefly introduced, including its organizational structure and product portfolio, where the logistics in the M1-axle hall, in which this final thesis is specialized, will be described in more detail.

The history of the Mladá Boleslav carmaker began with the construction of bicycles under the brand name Slavia in 1895 by mechanic Václav Laurin and bookseller Václav Klement. The inventors did not stick with the bicycle for a long time and quickly moved on to construct motorcycles and in 1905 Laurin and Klement entered the automotive industry with their first car Voiturette. Later in 1905, the company began exporting vehicles abroad to Australia, Japan, and Russia. The brand's new automobile models have already been designated as ŠKODA in 1925 and the first success was the ŠKODA POPULAR model, which has been a bestseller in 1934. In the same year, ŠKODA has launched ŠKODA RAPID, which was considered as a relative to ŠKODA POPULAR. The crowning glory came at the end of the fruitful year 1934 when ŠKODA 640 SUPERB was introduced. An important turning point was in 1991 when ŠKODA became part of the Volkswagen Group. ŠKODA became the fourth brand, next to the VW, Seat, and Audi brands. The Czech government chose this Group following the decision to sell a part of the stock. This link has proven crucial to the future success of ŠKODA. Financial resources were put into the company, foreign specialists worked on model creation and design, and the quality of the models and brand image improved. The largest foreign plants are in China, India, and Russia (ŠKODA AUTO, 2021).

ŠKODA is a joint-stock company in Mladá Boleslav and is the largest automotive manufacturer in the Czech Republic. The company is the largest Czech exporter, one of the largest Czech employers, and has long been the largest company in the Czech Republic in terms of sales. The company has three production plants in the Czech Republic, the main plant is in Mladá Boleslav and it is also the largest with almost 28 000 employees. The other two subsidiary plants are in Kvasiny with around 8 000 employees and Vrchlabí with 850 employees. The plant in Mladá Boleslav supplies the production with the components for ŠKODA and Group brands such as engines, transmissions, axles, and PHEV (Plug-in hybrid electric vehicle) batteries. Whereas in the plant in Kvasiny the new ŠKODA SUPERB iV plug-in hybrid is being manufactured and in the plant in Vrchlabí is the production of a DQ200 automatic 7-speed direct-shift gearbox (DSG).

5.1 Products of the company ŠKODA

Over the last 125 years since the company has been founded has become a company that produces multiple models with various design variants (Figure 8). It has thus become a competitive company worldwide. ŠKODA has numerous production sites abroad such as in China, Russia, and India. In the last few years, ŠKODA has also been producing cars from the Group, the SEAT Ateca model in Kvasiny. Volkswagen's management also plans to produce a new VW Passat model on the same production line as the ŠKODA SUPERB. In 2020, the production of the first ŠKODA ENYAQ iV electric car started in Mladá Boleslav. The average production output in Mladá Boleslav is 2 400 cars and in Kvasiny are 1 100 cars being produced per day (ŠKODA AUTO, 2021). The current model range by ŠKODA in the Czech Republic (see Figure 10) is as follows:

- Production in Mladá Boleslav: FABIA, SCALA, OCTAVIA / OCTAVIA iV (plug-in hybrid drive), KAMIQ (City SUV), KAROQ (Compact SUV), ENAYQ iV (first all-electric SUV),
- Production in Kvasiny: SUPERB / SUPERB iV (plug-in hybrid drive), KODIAQ (Large SUV), KAROQ (Compact SUV), SEAT ATECA.

Figure 10: Current model range of ŠKODA

Source: ŠKODA AUTO (2021).

5.2 Organizational structure

This next brief subchapter will focus on the description of ŠKODA's organizational structure for the department of Concern of Component Logistics/Management (PKL).

The department is in charge of all logistical activities, including planning for the successful operation of production at the Component Production (PK) plant in terms of quality and demands relating to internal and external customer supply. PKL focuses on topics-related activities such as:

- planning and management of aggregate production;
- material handling and transportation;
- deliveries to Group customers.

The department of PKL (see Figure 11) consists of the Head of Component Production Logistics, which is then divided into 3 main sectors with a coordinator in lead. The responsibility of the coordinator of components production manager is to provide production planning for engines, gearboxes, axles, and metallurgical components within the PK plant for the needs of

ŠKODA, the Group, and external customers. This department of production management provides dispatch controls of the production program, with the goal to ensure a smooth flow of production. The department of logistics service ensures the maintenance and operation of logistics systems, as well as the monitoring and compliance with economic and personnel indicators and the implementation of logistics projects.

In the sector of material management under which axle production is lying beyond the purview is the coordinator responsible for receiving, storing, and distributing materials and ensuring that assembly lines have a constant supply of material. The responsible leader coordinates the in-plant transport and handling equipment functioning at the PK plant such as:

- warehousing management in halls M1, M2, M6, and metallurgical plants;
- managing the supply of PK plant products to internal and external customers;
- customer management;
- packaging and transportation of spare components;
- providing external kanban supplies.

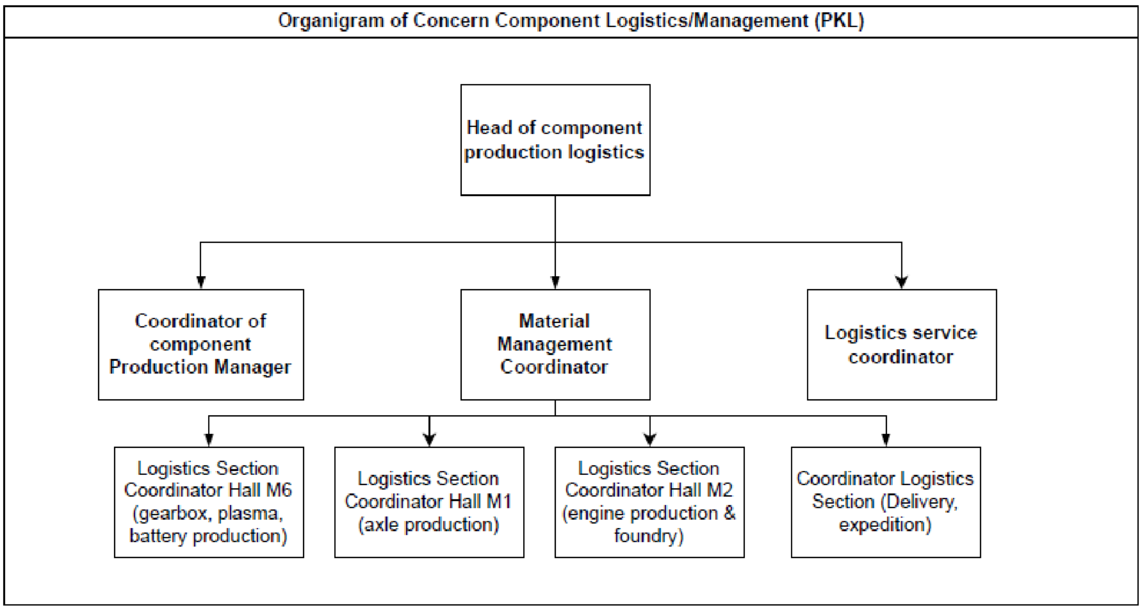


Figure 11: Logistics PKL organigram

Source: own processing (2022)

The department of material management is divided into 4 subdepartments based on which halls are the departments and the production situated. The author will focus on the relevant axle production department (situated in hall M1). This sector itself will be introduced in the next chapter.

PKL's material flow begins with a supplier who delivers the company with units. Part of the goods is subsequently moved to ŠKODA's central warehouse, while the remaining is transferred directly to the company's warehouses in its plants. Internal logistics then transport particular goods to designated halls for processing. The material traveling to the assembly of components must pass through the supermarket, where the workers prepare the components for each particular assembly line. Units for the automotive assembly process are shipped sequentially or in batches. After that, the final constructed car is shipped to the end customer. ŠKODA also supplies finished components to the end customer. The whole process of material flow of PKL through each department is visually shown and labelled in appendix A.

5.3 Introduction of the hall M1

The overall business of the company is divided into several divisions, but this thesis specializes in the axle production division, specifically the plant located in Mladá Boleslav. The first axle which was produced in Hall M1 was in the year 1969, later in the year 2000, the first set of shock absorber units started to be manufactured. Following that the first multi-link rear axle was manufactured in 2004 and last but not least the first electronically-driven axle was made in 2020.

Hall M1 is divided into two parts M1A and M1B. In hall M1A, the following activities are carried out:

- unit assembly;
- door assembly line;
- assembly line;
- inspection and overhaul activities at checkpoints;
- functional testing;
- water tests of automobiles.

Hall M1A is the main assembly sector for mounting car models such as KAMIQ, SCALA, and FABIA. Axle production is being processed in the other part of the hall M1B. An average of 1 260 cars are produced in 3 shifts per day in hall M1. The other production halls M13 and Kvasiny produce 1 200 cars in one day. The main products which are being mounted here are axles and shock absorbers which are depicted in Figure 12 and described with roman numerals.

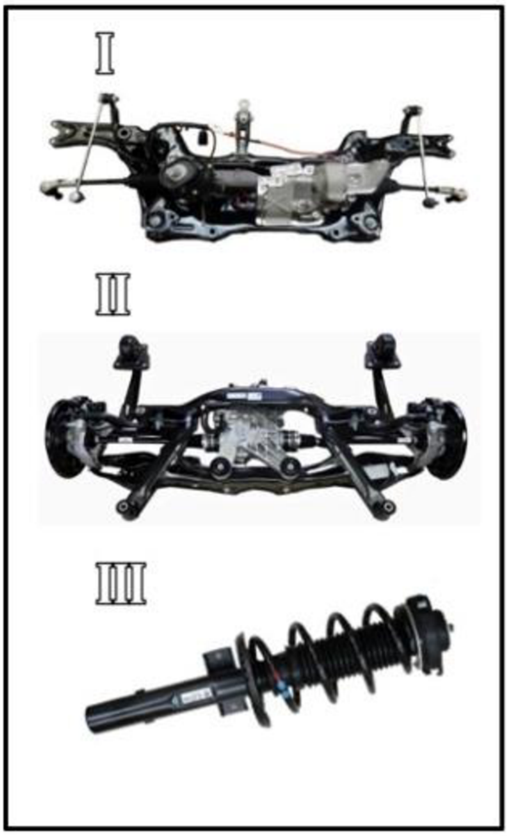


Figure 12: Product portfolio (I. front axle, II. rear axle, III. shock absorber)

Source: Dvořák (2022)

In hall M1B of ŠKODA, there are 11 assembly lines which are shown in Figure 13. To be more specific the individual lines are:

- two axle assembly line for Modular Electric drive matrix (MEB) (points 10, 11);
- nine front and rear axle assembly lines (points 1, 2, 3, 5, 6, 7, 9);
- two shock absorber assembly lines (points 4, 8);
- block stocking warehouse (point 12).

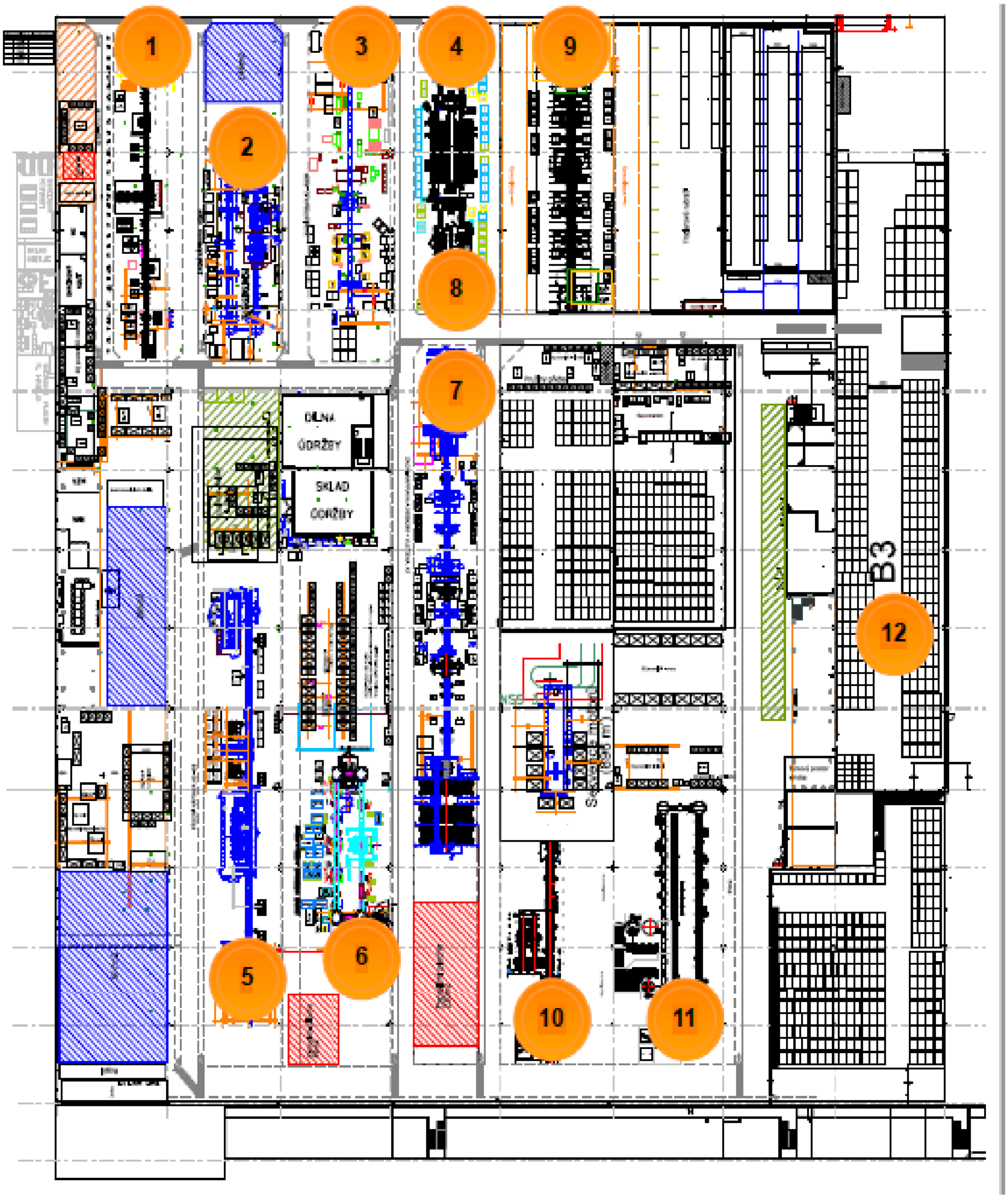


Figure 13: Layout of hall M1B

Source: own processing (2022)

As shown in Figure 14, axles and shock absorber units for ŠKODA FABIA, ŠKODA OCTAVIA, ŠKODA SUPERB, ŠKODA KODIAQ, SEAT ATECA, ŠKODA KAROQ, ŠKODA KAMIQ, ŠKODA SCALA models are mounted here. The final parts are then transferred to the assembly line in hall M1A and assembly for Kvasiny, where the components are being mounted into the final product. Some axles are also sent to foreign plants, although these operations are not included in this thesis and therefore the author will not take it in consideration.

	FABIA	SCALA	KAMIQ	OCTAVIA	ATECA
Front axle	✓	✓	✓	✓	✓
Rear axle	✓	✓	✓	✓	✓
Shock absorber	✓	✓	✓		✓

	SUPERB	KODIAQ	KAROQ	ENYAQ
Front axle	✓	✓	✓	✓
Rear axle	✓	✓	✓	✓
Shock absorber			✓	✓

Figure 14: Product portfolio of components of Hall M1

Source: Dvořák (2022)

ŠKODA produces axles and shock absorber units in batches and in sequence. The products that are being sent to ŠKODA must be examined and taken over from the driver. After the goods are unloaded from the truck, they are placed in a defined location in the warehouse, such as a rack or a block position on the floor. The parts are kept in the warehouse until they are needed for production. The parts are then authorized for production and sent to the assembly lines. The production process is working on a JIS basis.

Sequential production means that orders are arranged in the order in point M100, where the products are subtracted from the main assembly from the hall M1B and transferred to the hall M1A to be mounted into the vehicle. This is a point in the production process where the welded body of the car is hung on a hinge and the assembly of the vehicle begins according to the individual specific design of the end customer. The vehicle identification number (referred to as KNR – *Kennnummer*) is also generated at this stage and this number remains the same till the vehicle is assembled and delivered to the end customer. The correct order must not be violated, as there would be a discrepancy when picking the axles, where the axle ready for assembly would not be intended for the vehicle chassis in order. The picking process must adhere to the production plan. Axles and absorber shock units for halls M1 and M13 are manufactured here in a sequential manner. All the components and units are provided with at least a QR code or a bar code.

Batch production produces several identical parts in a sequence, the production requirement is entered according to the grade (a certain type of part) for entire pallets – each pallet contains just one type of product. This is how axles and shock absorber units designed for Kvasiny are manufactured.

The axles and shock absorbers each are labelled with a QR code or a bar code for identification, which are being scanned by a Personal Digital Assistant (PDA) scanner and sent off to e-paper placed on the cart for the preparation of units for shipment to assembly lines. Axles designed for the assembly line in Hall M1 are transported on special metal pallets equipped with a chassis. These pallets are transported to the assembly line either by workers using a Jungheinrich tugger or by an AGV from CEIT. AGVs can move where the hall's infrastructure is adapted to this. Magnetic tapes must be built into the floor to navigate the AGV and, in some places, RFID tags to give commands to the tugger. The numbers on the pallets are important for maintaining the correct axle sequence, and their order must not be reversed.

6 Analysis of the current business operations

This chapter is an analysis of the current state of lean logistics in the selected company, which will serve together with the part devoted to the research as a basis for the final assessment of the overall situation and final recommendations. All the following findings are based on the company's internal resources. Data about the company were provided based on the *Final Thesis Processing Agreement*; under this clause. The author of this thesis has received internal documents in the form of presentations, process flow descriptions, and work instructions from the company that is researched being done for. Furthermore, data on particular passages were gathered through discussions with the consultant or other responsible parties.

Consultation with the manager of internal logistics processes identified an insufficiently efficient process of logistics handling equipment from the charging station back to the warehouse. The current state of the logistic process of axle production will be analyzed and described in this chapter.

6.1 The charging station in hall M2

The capacity of the charging station (Figure 15) is given by the project. The number of charging devices in hall M2 is currently a total of 65 stations. Only a person authorized and demonstrably trained in accordance with the operating guidelines may operate the charging station equipment. During the actual work, it is then required to follow the instructions of the manufacturer of traction batteries, chargers, and instructions for the relevant handling equipment and product for handling batteries to provide the best results possible. The manual for the battery change (Figure 16) for the handling equipment is as follows.

Figure 15: Charging station in Hall M2

Source: own processing

1. The handling equipment is parked at the M2 charging station's handling area.

2. The operator of handling equipment hangs non-static clothes on the hanger next to the door and discharges static energy by placing his palm on the discharge plate next to the door. When replacing the battery, the operator must wear leather gloves due to safety regulations.

3. The operator will identify himself with the help of the personal card of the company by attaching it to the reader machine. Reading data from a personal card is signaled by the green light turning on which signals the operators approval to proceed to the next step.

4. The operator identifies the RFID tag of the discharged battery. After reading the data, another light on the indicator turns on.

5. Charging points for locating and connecting a discharged battery and removing a charged battery are offered on the corresponding display on the wall of the charging station. There might be a situation when the system does not supply a charging port to the operator, this signifies that there is no free-functioning charging port for the handling equipment since hall M1B shares the charging station with hall M2.

6. The operator places the discharged battery in the marked charging point, where it unlocksthe device from the automatic refilling demineralized water connector (Figure 17) before inserting it into the charging point in the device.

7. The operator then removes the battery cover and unlocks it, separating the connector from the cart connector. The operator uses a low-lift truck to retrieve the discharged battery from the handling equipment and secure it for handling preparation.

8. After placing the battery on the charging station, the worker secures it on the manipulator.

9. The operator removes the charged battery from the charging point using the low-lift truck; if using the handling tool, the operator must unlock the battery on the handling tool, insert the battery into the handling equipment, secure the battery and connect the battery connector, and close the battery cover on the handling equipment.

10. The operator returns the low lift truck to the assigned station after handling the low lift truck from the charging station and then removes the leather gloves.

11. The operator releases the parking brake and exits the charging station.

Figure 16: Battery changing process

Source: own processing

Figure 17: Lead-acid battery with a close look at the connector (demineralized water and electricity connector with a handle)

Source: own processing

Ongoing inspection of charging sources, maintenance, or possible repair is provided by an external company that ŠKODA outsources these tasks. Monitoring of the state of air conditioning to ensure that all generated harmful gases are completely removed is also provided by an external company. At the completion of charging, traction batteries must be topped up with distilled water; this procedure is automated for efficiency purposes. During battery charging, malfunctions may occur, such as overheating of the battery and being destroyed, or acid or other substances (other than water) leaking into the suction. These faults have to be immediately rectified by the external company who are responsible for the function of the charging station. Due to that daily maintenance is performed at the charging station to insure everything is working and is in line with the regulations. The workers visually inspect the batteries for signs of damage. They focus on the insulation of cell connectors, if they are broken, cables, connectors, mechanical damage to battery cell caps (cracks), expanded electrolyte on cell caps, oxidation at pole terminals, etc. The external company then secures the maintenance on a weekly and monthly basis to make sure everything is running smoothly.

6.2 Sequential workplaces in hall M1B

Currently, logistics personnel in hall M1B are engaged in 14 sequential workplaces. All the sequential workplaces are in detail described and depicted in appendix B. These employees load sequential parts into sequential carts in accordance with the information shown on the display of the e-paper.

Since 2020, after the introduction of e-paper technology (electronic paper), all printers and paper sequential stickers have been eliminated from sequential workplaces. It is a passive display that uses power only when information is sent from the server to the display. It includes all of the relevant information, such as the barcode, recall number, part number, part code, and part number including vehicle type and location, and placement in the sequential trolley. With the e- paper the operator is not required to take the sequential stickers out of the printer. Sequential stickers will be shown digitally on the tablet screen. The system is intended to permanently reduce the cost of operating sequential workplaces and the amount of waste of papers. Data is delivered from system called SoFISt II to wifi points through the LAN network, which wirelessly distributes data to individual sequential tablets. The data is transported from the tablet to a small ePaper, which is attached to a sequential trolley.

The control system is deployed at all 14 sequential workplaces. The personnel picks 13 290 parts in one day. The numbers of the units on the pallets are important for maintaining the correct axle sequence, and their order must not be reversed.

Each sequential workplace has multiple handling equipment responsible for supplying and transporting materials between the hall M1B and the passage of halls. The author will focus on 2 types of handling equipment, that have the longest and frequent routes in the hall between the sequential workplaces. The selected types of handling equipment are forklift 4.5 t and forklift 5.5 t. As stated in chapter 2.1.1. there are 4 pieces of forklifts 4.5 t and 5 pieces of forklifts 5.5 t. The route of the travels of each forklift 4.5 t and a regular route of forklifts 5.5 t are depicted in appendix C.

Each of the forklifts 4.5 t is responsible for 1 task. The responsibilities are as follows:

- Export of produced axles for assembly hall M13 from assembly lines L6 and L7,
- Export of produced axles for assembly hall M13 from assembly lines L10 and L11,
- Withdrawal of produced axles from assembly lines L5 and L6,
- Export of empty packaging.

The responsibilities for forklifts 5.5 t are mainly in the passage of halls M1 and M2, which are located outside. The main point of forklifts 5.5 t is expedition of materials in and out between the hall and the passage of halls and for loading and unloading supplies, where the trucks deliver and pick up the goods.

6.3 The current state of handling technology process

During the production of the axel based on the sequential process, manipulation technology is often used. The everyday schedule of an operator on the handling equipment is highly demanding. When the battery runs out it is necessary to stop the process and go recharge the lead-acid battery which is stationed in a separate hall. When recharging the battery the employees have to leave the work hall due to the fact that the recharging station is located in Hall M2, which is a completely separate location from the work hall.

The lead-acid battery has the limitation that when left for an extended period (several days) in an insufficiently charged (or discharged) condition, its electrodes develop a condition known as sulfation, which significantly reduces its capacity. Issues may also arise if the lead-acid batteries are charged. Three possible causes such as an increase in battery temperature and subsequent destruction, leaking of acid or other substances into the suction of produced gases, or the development of hydrogen generated during water electrolysis into an electrolyte, which generates an explosive combination with oxygen are dangerous for the users. Therefore, everyday maintenance is a must for the charging station to be a safe place to the employees and to store such a large number of batteries, which ends up being costly for the company. The calculation of costs of the services provided by the external company will be stated in chapter 8.1. Nonetheless, it is still the most extensively used source of electricity storage in ŠKODA.

The author has chosen the longest distance of traveling, that an operator of handling equipment has to drive through the hall, to get to the charging station for both chosen types of handling equipment. The measurement and future calculations are to visualize the route and time to the charging station. The route of the operator´s travel is depicted in the layout below (Figure 18). Since there are 32 pieces of handling equipment with lead-acid batteries in hall M1B, it is challenging for the material flow in the logistics to deal with operators who are engaged with recharging the battery. There are times when more than two operators must leave the workstation to travel to the charging station because the lead-acid battery cannot be predicted nor planned when it will be discharged. This circumstance thus causes delays in the delivery of supplies to assembly lines or the loading or unloading of goods from or onto trucks, which are waiting in the passage of halls M1 and M2.

Figure 18: Visualization of routes from block stacking points to charging station

Source: own processing

The author calculated the measures conducted from research in the hall M1B. First of all, the expression for the permitted speed of a handling technology in ŠKODA will be stated. According to the ŠKODA working rules, the fastest speed for the handling equipment is allowed up to 10 km/h due to safety reasons. The longest route for one of the most used handling technology designated for transportation of heavy pallets with goods is for forklift 5.5 t, which is measured from when the operator drives from the block storage (shown on the map by point A – forklift 5.5 t) to the charging station. The total route (there and back) is 680 m.

The author also measured the length of the route for the 4.5 t forklift, which is the second most frequently used handling technology in the hall M1B for manipulating heavier pallets with goods (shown on the map by point B – forklift 4.5 t). Its route to the charging station (there and back) is 520 m. The author has measured the distances with a distance measuring wheel to get the more accurate measurement of the routes when calculating the distance.

The time to travel with the depicted route from point A and point B to the charging station has been calculated by the sample depicted by the formula (1).

$$t = \frac{s}{v}, \tag{1}$$

where:

t – time,

v – speed[1],

s – distance.

The specific calculations are provided below.

$$t\ (5.5\ t) = \frac{680}{2.77}$$

t (5.5 t) = 245.5 s = **4 min**

$$t\ (4.5\ t) = \frac{520}{2.77}$$

t (4.5 t) = 187.7 s = **3 min.**

The calculations of forklift 5.5 t travel indicate that the operator of the handling equipment requires 4 minutes, even with the return route from the charging station. The route of the forklift 4.5 t is slightly shorter in comparison to the route of forklift 5t. **The travel including the return route was calculated up to 3 minutes for the forklift 4.5 t.**

From the internal information from the employees and the measurement of the charger exchange for the handling equipment, the total time is approximately 15 minutes per one handling equipment. **The overall duration of traveling the route to the charger station, including battery replacement, is ca. 18–19 minutes** depending on the path and the type of handling equipment. **The operator of the handling equipment has to spend this time from his working time, which can be considered as a waste of motion, movement and waiting**.

[1] The unit of speed was converted into m/s, which is expressed by speed unit (10 km/h) divided by 3,6.

Operators of handling equipment do not have a reserved parking location in the workplace where they may park when taking breaks or changing shifts. In the warehouse, ŠKODA follows a general guideline of parking on the sides of block stacking areas, where it is safe, and leaving enough room for employees passing by, which can cause chaos in the working place. Due to that the accident rate in the hall is on an average scale currently.

7 Proposal for solving shortcomings

In this chapter observation, self-research, and the study of professional materials were employed. To save costs and reduce wasted time on unnecessary movement, this chapter of the diploma thesis will outline the author's recommendations. This can be done based on the analysis performed current status of the lean management application.

Following an analysis of the current state of battery charging for handling equipment in hall M1B. The operator is inefficiently using valuable amount of working time for traveling across halls to recharge the equipment. The author will propose a new solution that will improve the usage of working time efficiently and effectively. This solution will show the break time to be maximally used for automated recharging, and there will be no requirement for any extra personnel manipulation. The author will focus on describing the performance and properties of the Li-ion battery, as well as calculating the charging time in greater detail and describing the layout of the suggested parking lot with built-in chargers.

Lead-acid batteries were one of the few options for powering material handling equipment like forklifts and pallet jacks, etc. for decades. However, quick technological advancements are creating a more even larger field, with choices such as Li-ion batteries, thin plate pure lead batteries filled with gel polymer electrolytes that may quadruple the life of the battery and a lead-acid battery. Meanwhile, warehouse managers just want a power supply that is low-cost, low-maintenance, and requires no downtime.

The attractiveness of Li-ion technology lies in the fact that there is no need to build or modernize charging rooms, which take up space and are a source of risky situations. There is no need to invest in a spare battery, the time is saved by not having to replace the batteries by driving to the charging station and there would be no need to hire external companies for maintenance of the batteries and the charging station. Another advantage is that this modernized technology eliminates the frequent accidents connected with battery replacements. Li-ion batteries are safely secure inside the handling equipment. The main two factors why lithium technology is 15% more cost-effective than conventional lead technology:

- The ability of the lithium battery to store the energy supplied by the charger (the lithium battery heats up less during charging resulting in less loss when storing energy in the battery).
- As a result of point one, there are fewer losses in the charger (battery management system controls charging).

Each battery module monitors the temperature and voltage of the cells, as well as the even distribution of energy between them. Both systems interact with one another, and if there is an unwanted discrepancy in voltage, temperature, or other parameters, the machine will be immediately corrected and possibly shut down. There are no gas leaks during charging, and no harmful acids are employed, compared to lead-acid batteries.

7.1 Battery performance

In the chart below (Figure 19) can be seen a graphical representation of a simulation of the correct battery performance for 1 day measured by Toyota for a reach truck within a certain period of the observation. The measurement was based on the defined battery capacity and the size of the charger with counted breaks and as well their length and intensity of operation. The level range fluctuated from 100 to 45 %. At regular two hours, 10-minute and 30-minutes breaks are alternated. Every break was used to recharge the batteries. The length of a 10-minute break was during 09:00, 11:00, 17:00, and 19:00. The 30-minute break was at 13:00, 15:00, 21:00, and 23:00. The simulator provides a quick graphical representation of the battery status and availability of the handling equipment within the monitored period, according to the defined battery capacity and charger size, the number of expected breaks, their length, and intensity of operation for each handling equipment type. The simulator makes it very easy and clear to select the correct and appropriate battery capacity and charger size (Toyota handling material cz, 2020).

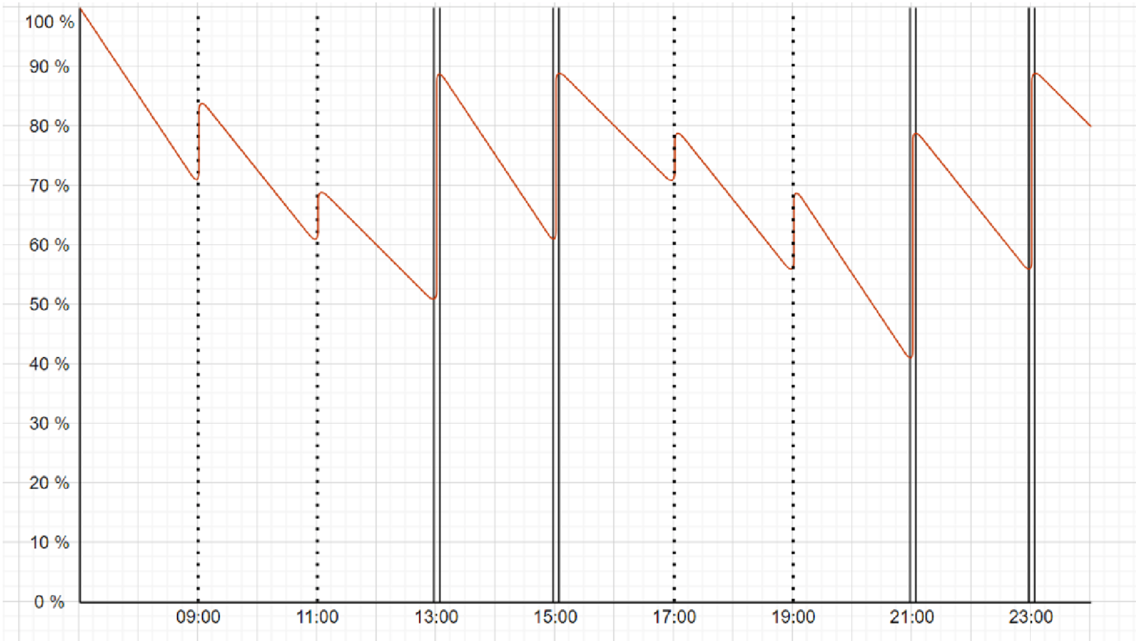


Figure 19: Simulation of battery performance

Source: Toyota material handling cz (2020)

ŠKODA runs a three-shift operation and each shift always has one break of 30-minutes for employees to rest and on top of that, there is a 10-minute break to pass the shift to the following operator and to disinfect the working place or used handling equipment after every shift ends, due to Covid 19 restrictions. Since ŠKODA has the same length of breaks as Toyota just with different break times, as shown in Figure 19, the battery charger for specific handling equipment can be applied after the conducted research from the simulator. The time of breaks in ŠKODA is from every shift the same, in ŠKODA the workers work in 3 shifts. The morning shift, which runs from 6:00 to 14:00, has a 30-minute break at 10:45. The afternoon shift starts from 14:00 till 22:00, where the break is for 30 minutes as well at 18:15 and the night shift starts from 22:00 to 6:00 with the break at 02:15. There is a 10-minute break before every end of the shift. The charger's theoretical capacity use will thus be 2 hours during the day (e.i. 8.3%, 2/24). While production is on hold and not in progress over the weekend, the batteries are being fully recharged that period. The night shift will start at 10 pm on Sunday, with the recharging process continuing as scheduled throughout the breaks.

A model example of the forklift 4.5 t is shown in table 2, where the technical data are described for that particular type of handling equipment. The amount of voltage required for charging a Li-ion battery against a lead-acid battery is compared. The battery capacity needed for the forklift 4.5 t is 500 Ah with a voltage of 86.4 V. These data are to be found with the connection of the charger 80/290 SLH 090i, which can be seen in appendix D. To recharge the Li-ion battery up to 50% would take 52 minutes and up to 100%, will take 103 minutes. The ultimate limit for battery discharge of handling equipment is 40% of the battery capacity, where the battery is not being harmed.

Table 2: Technical data to a model example of forklift 4.5 t

Technical Data		
Battery voltage lithium-ion-battery	V	86,4
Battery voltage lead-acid-battery	V	80
Lithum-ion-battery		
Battery capacity	Ah	500
Minimal remining charge (min. SOC)	%	40%
Efficiency enhancement battery	%	10%
Other tolerances (ageing, other uncertainties,...)	%	1%
Charger		
Charger (example: SLH090i 24/100)	A	290
Charging-performance "C" (max 1)		0,58

Source: Jungheinrich (2022)

The author has calculated the average percentage of battery recharge during the 30-minute and 10-minute breaks of the particular forklift 4.5 t by the formula (2), where:

T_{rt} – total recharge time up to 100% (in minutes),

B_{30} – 30-minute break (in minutes),

B_{10} – 10-minute break (in minutes),

R_t – total percentage of recharged battery (in percent).

$$R_t = \frac{B_{30}}{T_{rt}} * 100 \qquad (2)$$

$$R_t = \frac{30}{103} * 100 = 29.13 \%$$

$$R_t = \frac{10}{103} * 100 = 9.71 \%$$

The handling equipment will be recharged **up to 29.13% during the 30-minute break**, and the battery capacity will **increase by 9.71% during the 10-minute break**.

Figure 20 depicts a model example of battery performance of a Li-ion battery for a forklift 4.5 t provided by Jungheinrich, which is customized specially for ŠKODA. The graph depicts the performance of a Li-ion battery on a daily basis over the course of a week. Each colour in the graph represents one day in a week and how long the battery will operate during three shifts with recharging between breaks. The example of breaks is listed in the table 3, where the regular 30-minute breaks are calculated. Extra breaks throughout the shift are incorporated into the table of breaks, because in practice, the handling equipment is **in active motion 5 hours out of 8 hours (based on operating hours)**, as can be seen in appendix F. Appendix F is a table with

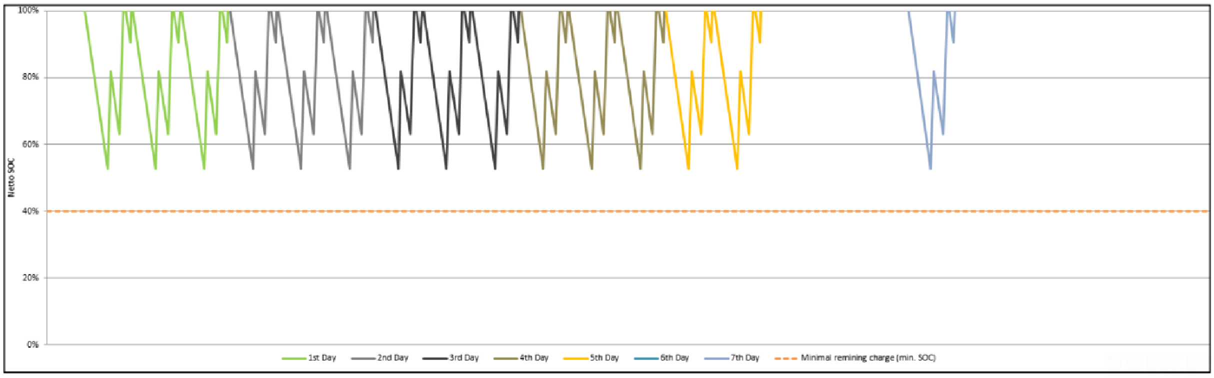


Figure 20: Model example of battery performance of forklift 4.5 t

Source: Jungheinrich (2022)

When the batteries are charged during breaks in increments of 29% in 30 minutes and about 10% in 10 minutes, then according to Figure 20, which shows the simulation for operation at the ŠKODA plant, there is always enough charge so that the average battery performance does not fall below 40%.

Table 3: Model example of breaks throughout 3 shifts

		1st Day	2nd Day	3rd Day	4th Day	5th Day	6th Day	7th Day
Start of work 1st shift		6:15	6:15	6:15	6:15	6:15		
1st break	Start	10:00	10:00	10:00	10:00	10:00		
	End	10:30	10:30	10:30	10:30	10:30		
2nd break	Start	12:00	12:00	12:00	12:00	12:00		
	End	13:00	13:00	13:00	13:00	13:00		
3rd break	Start							
	End							
End of 1st shift		13:45	13:45	13:45	13:45	13:45		
Start of work 2nd shift		14:15	14:15	14:15	14:15	14:15		
1st break	Start	18:00	18:00	18:00	18:00	18:00		
	End	18:30	18:30	18:30	18:30	18:30		
2nd break	Start	20:00	20:00	20:00	20:00	20:00		
	End	21:00	21:00	21:00	21:00	21:00		
3rd break	Start							
	End							
End of 2nd shift		21:45	21:45	21:45	21:45	21:45		
Start of work 3rd shift		22:15	22:15	22:15	22:15			22:15
1st break	Start	2:00	2:00	2:00	2:00			2:00
	End	2:30	2:30	2:30	2:30			2:30
2nd break	Start	4:00	4:00	4:00	4:00			4:00
	End	5:00	5:00	5:00	5:00			5:00
3rd break	Start							
	End							
End of 3rd shift		5:45	5:45	5:45	5:45			5:45

Source: Jungheinrich (2022)

Each handling equipment requires its own type of battery charger plug. The type and the size of the charger as well as the battery charger plug are determined by the voltage that is compatible with the specific handling equipment. The charging times for each type of charger with a specific voltage are depicted in appendix D. The table in appendix D also indicates the charging time in minutes when the handling equipment with a Li-ion battery is charged to 50% or 100%. There are 4 types of chargers plugs suitable for ŠKODA's handling equipment that is leased by an external company (Jungheinrich) (see Figure 21):

- A Schuko 230 V/ 16 A for voltage of 24 V,
- CEE C1 400 V/ 16 A for voltage of 24 V,
- CEE C2 400 V/ 32 A for voltage of 48 V,
- CEE C3 400 V/ 63A for voltage of 80 V.

Figure 21: Types of charger plugs

Source: Jungheinrich (2022)

7.2 Implementation of proposal

The author will describe the implementation of her recommendation for improving the current state of the logistical process in hall M1B in the following subchapter. The author begins by comparing lead-acid batteries with Li-ion batteries. Following that, she will outline the suggested parking lot layout with charger stands inside M1B hall. The design will be endorsed by a basis in the form of a simulation design based on an analysis of the company's layout. Data on logistics is based not only on personal consultations with the persons responsible for their operation but also on internal materials in the form of presentations, descriptions of process flow, and work instructions.

The lead-acid battery offers the advantages of low cost, low-temperature tolerance, and cost-effectiveness, but the disadvantages of low energy density, short life, huge volume, and poor safety. Electric Vehicles used as power cannot have a high cruising range or a high speed because of their low energy density and service life. They are often suited for low-speed vehicles. Whereas **the Li-ion battery** is now one of the most technologically sophisticated batteries. This type of battery has a high energy density and can store more electricity; it has a long cycle life, can be charged and discharged several times, and can be used for an extended period of time. There are two kinds of lithium batteries utilized in electric vehicles nowadays: lithium iron phosphate batteries and ternary lithium batteries (Wang, 2022). In consideration of the advantages and drawbacks of Li-ion and lead-acid batteries, the author has proposed a solution that is both cost-effective and beneficial to the company.

There are in total 32 handling equipment for the hall M1B, which means there has to be for each handling equipment a charger being placed in the hall always nearby to the canteen or their frequently working area (as seen in Figure 22). This way the motion and movement of the operator in the hall and the charging station can be reduced, and the time of the break can be fully used for personal activities or resting of the employee. No or less time will be taken from the breaks of the operators and the accident rate will decrease, since each type of the handling equipment will have its own parking lot. There is one canteen for the logistics department in the hall M1B.

In the following layout (Figure 22) the author has mapped out the canteen station for the department of logistics and the proposed charging stations for the handling technology situated in the hall. Numbers in green circles depicted in the layout below mean, how many charging stations will be situated in that specific area. The handling equipment from the company Still is mostly used for outside transportation in the passage of halls M1 and M2 and for manipulation of heavy pallets with goods, therefore the charging station for in total of 5 forklifts 5.5 t will be situated on the outside wall of hall M2, marked in the layout (Figure 22) with a STILL sign.

The passage of halls M1B and M2 has a roof cover, as seen in appendix E. This way it will prevent any adverse conditions that may occur. The storage capacity for empty packing was increased as well by roofing the passage of halls between M1B and M2.

The proposal of the author suggests installing 4 chargers on the pillar in the production hall M1B across the canteen, as well as 1 charger for a tugger in a storage area, where it is mostly used. The following 11 chargers will be located in an area next to the canteen. There will be a designated parking lot with the charger stands. The parking lot between the pillars will have a perforated wall from steel (see Figure 23) to install the chargers in that area. The remaining 11 chargers will have a parking lot between the pillars, which will be across the parking lot next to the canteen.

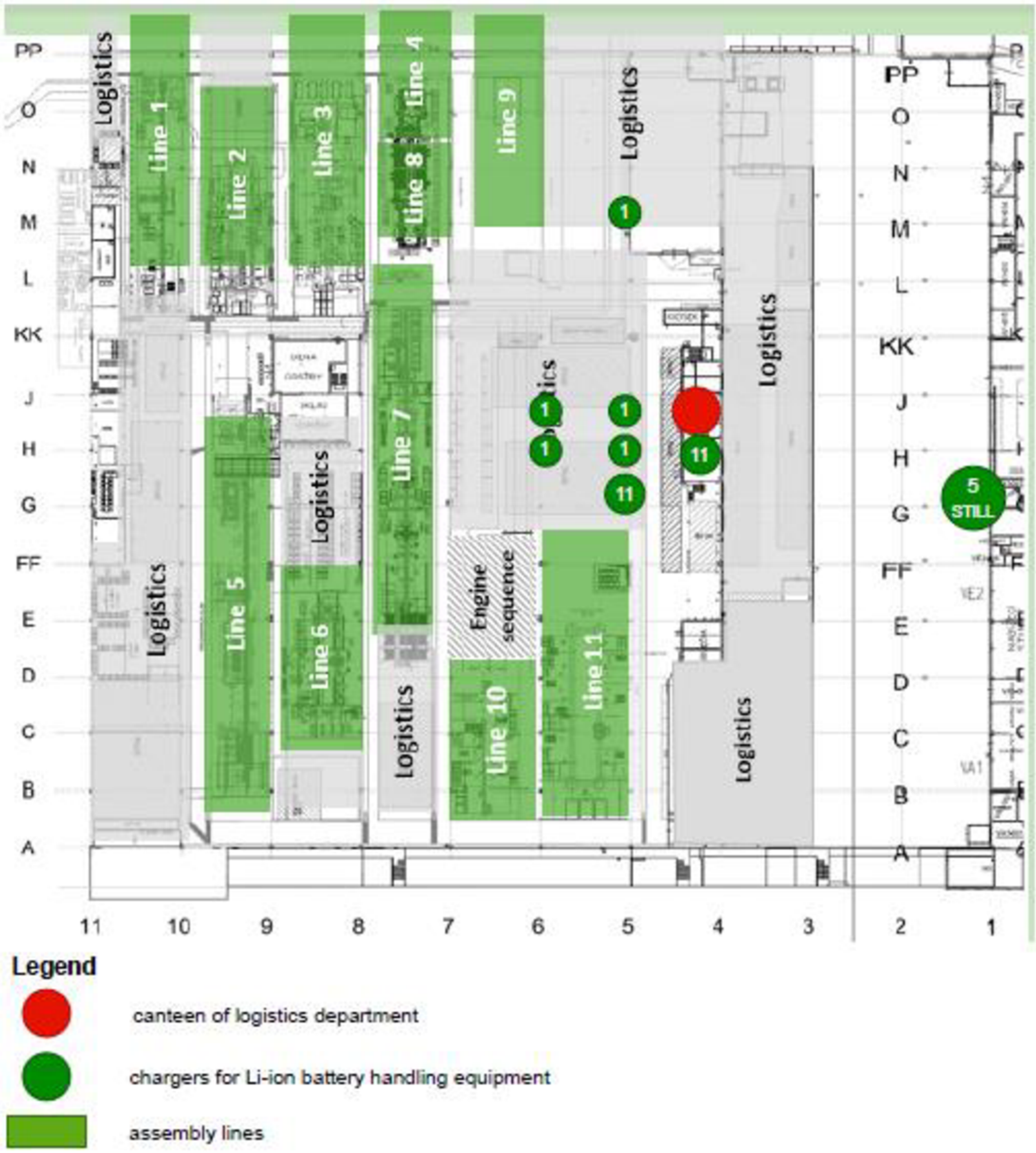


Figure 22: Layout of Hall M1B with charger station for Li-ion batteries

Source: own processing

Figure 24 shows possibilities for how to locate the stands with the chargers. The charges illustrated may be installed in 2 different ways. The left charger may be installed on the wall or in the pillar, but it cannot be moved, whereas the charger on the right side is held by a stand, which is possible to move around and adjust the placement of the charger. The charger with a stand does not require any specific modifications for the installation of additional electrical outlets. The chargers are dependent on the handling equipment's voltage. There are 4 different types of charges, each of which corresponds to various types of charger plugs. The voltage level that is expected to flow into the handling equipment is modified on the connector that is plugged into the vehicle to charge the handling equipment.

Figure 23: Proposed parking lot for handling equipment with Li-ion battery between pillars

Source: Kaiser + Kraft (2022)

Figure 24: Chargers for Li-ion batteries (left – charger installed on the pillar, right – charger stand)

Source: own processing

ŠKODA will be able to save space by replacing lead-acid batteries with Li-ion batteries. Instead of having an additional charging station with 65 stations in it and requiring an everyday basis check-up and maintenance. In the mentioned space there could be a concept for new warehouse storage of goods and components. ŠKODA produces a significant number of products and components and is limited in warehouse storage space; this concept will save the company expenditures by eliminating the need to rent an external storage facility, external company for maintenance of charging stations and the batteries, and decreasing extra costs on ineffective time of personnel, which is spent on changing batteries.

Operators currently need to travel to the charging station passing through the passage of halls, which means having to ride outdoors. By adopting the proposed suggestion of replacing the lead-acid batteries with Li-ion ones, in the winter season, the operators will not need to receive any extra clothing from the company since they will not be required to travel between the passage of halls to reach the charging station. This will reduce the cost of work clothing, as well as reduce the possibility of the operator colliding with the trucks while they are being loaded and unloaded with the goods in the corridor, and in general, the accidents rate will be lowered.

7.3 Battery disposal and recycling

This subchapter is devoted to describing how Li-ion batteries are treated when their lifetime has expired. The features of the many varieties of batteries that are hazardous or not to the environment are also depicted. The current company's service to ŠKODA is also addressed when it comes to their treatments for expired batteries.

In the last few years, the share of electric handling equipment with Li-ion batteries has increased significantly. Li-ion batteries are very durable and therefore typically outlast the handling equipment itself. The reuse of lithium-ion batteries after years of use in electric handling equipment is an efficient, sustainable, and resource-saving step towards a sustainability strategy. Lead recycling is an important part of helping to fulfill the world's rising need for electricity. It means companies can offer critical supplies while still leaving a lower environmental impact. Lead batteries supply 70% of all rechargeable battery energy storage capacity globally, and 99% of the materials needed to make lead batteries may be recovered or reused. In fact, lead batteries are the most recycled consumer product on the planet, with recycling accounting for more than 80% of the lead supplies (Ecobat 2022).

Due to the wide range of supplied batteries, galvanic cells and accumulators, the following classification system is specified:

- Group 1 – contains no hazardous features:
    - alkaline,
    - zinc-aluminum,
    - lithium,
    - silver-oxide,
    - AKU-LION (mobile phones).
- Group 2 – possesses hazardous features (lead batteries):
    - Aku-Ni – cadmium NiCd,
    - Aku-Ni – metal hydroxides NiMH,
    - Aku-lead – hematic Pb (in emerging lightnings),
    - Aku-lead – starting for cars (Turková 2017).

The reuse of Li-ion batteries in secondary applications extends their lifespan and enhances the advantages of their use; recycling appears to be one of the most promising methods for dealing with End-of-Life Li-ion batteries. Recycling enables the recovery of valuable metals, the security of the alternative materials supply chain, and independence from exporting economies. As a result, all aspects of the techno-environmental-economic character are impacted. According to recent studies, the recycling operations of retired automotive Li-ion batteries often begin with pretreatment, which entails discharging, dismantling, and any form of treatment (chemical, thermal). Recycling techniques are defined as **metallurgical/mechanical procedures**, which include industrially extended pyrometallurgical and hydrometallurgical technology, and **laboratory examined direct recycling**. Both techniques, industrial and laboratory-driven recycling, complement each other in order to achieve the optimum level of material recovery efficiency. Nevertheless, the recycling process is environmentally harmful, and its execution is outrageously costly (Pražanová et al., 2022). The economic benefits are the driving factor behind the circular value chain's operation. As a result, the cost of remanufactured and reused Li-ion batteries should continue to decrease in order to compete with new batteries. During the recycling process, simple operating procedures, low-cost materials, decreased energy usage, and environmental friendliness is necessary (Hua 2020).

The final and professional decommissioning or disposal of the handling equipment must be carried out in accordance with the legal regulations in force in the country of use. In particular, the regulations for the disposal of batteries, consumables, electronic and electrical equipment must be followed. Only properly trained and certified persons may uninstall the vehicle, provided that the manufacturer's instructions are followed.

ŠKODA has designed a program known as "second life" for obsolete lithium batteries. ŠKODA employs batteries with residual capacity to build energy storage facilities with the cooperation of a partner company. Batteries that cannot be utilised in the energy storage plant are subsequently transported to responsible recycling partners by ŠKODA (ČTK České Noviny, 2021). One of the major responsible companies is Jungheinrich, that is providing the disposal of Li-ion batteries. Since Jungheinrich is not in the position to recycle batteries on its own, the company JT Energy System is supporting them. To guarantee optimal lifespan, used batteries are checked and, if necessary, refurbished. JT Energy Systems is building a 25-megawatt stationary energy storage facility in Freiberg, Saxony, utilizing recycled Li-ion batteries. The megabattery's purpose is to provide intermediate storage of regenerative electricity, to stabilize the energy network, and provide urgently required energy at peak times. Stationary energy storage systems, such as the one in Freiberg, are a logical result of the usage of Li-ion batteries for a second life, and thus make a significant contribution to the transition to new energy. JT Energy Systems repurposes discarded Li-ion batteries and plans to produce emission-free batteries in the future (Jungheinrich AG, 2021).

8 Economic evaluation

This subchapter describes the economical evaluation of the proposed implementation. The author as well shows the calculations of the different expenses between the lead-acid (current type of battery) and Li-ion battery (proposed type of battery). The conclusion of this chapter will be the overall calculation comparison of the costs of both types of batteries.

Savings and returns will be calculated for changing the type of batteries in the handling equipment. Without a doubt, this will make manual management of handling equipment in the company easier. Logistics processes will also speed up. This investment will pay off and the savings and return will be calculated as well. Replacing the charging system from now on will bring savings. These savings will result from the elimination of current personnel costs for battery replacement. In the current situation, the operator must manually replace the battery. The suggested adjustment removes the whole procedure. This equates to huge cost savings over the course of the working year. Additional savings will be realized by minimizing the number of operational costs. It is a technology that contributes to ecology and saves space. And so, it saves the traffic that is associated with it. Spending money on new batteries over the next decade will not be large. Its return will be calculated using the total expenses estimated for the installation of new charging stations and batteries. This is accomplished by calculating the year's savings.

The current expenditures, that the author has been mainly focusing on, for handling equipment with lead-acid batteries in hall M1B and later are depicted in calculation tables for each type of battery are as follows:

- **Charging station costs** are being calculated regarding 1 m^2, which ŠKODA pays for the extra area (in this case it is 1,000 CZK/ 1 m^2).
- **Personnel expenses** for battery replacement – Each battery change takes the operator around 15 minutes. Hall M1B has in total of 32 handling equipment and is working on a 3-shift operation. The total expense on personnel has been multiplied.
- **Demineralized water costs** are calculated by how many liters of water it is needed to refill the charger with.

- **Battery repair costs** – Every spare lead-acid battery has to be charged by connecting the handle to the electricity and demineralized water connector. It is possible, that the handle breaks (as seen in Figure 25), and ŠKODA will be responsible for having it repaired by an external company, therefore the costs occur. Whereas Li-ion batteries are built into the handling equipment, there is no need for the operator to manipulate the battery and therefore no service or repairs are needed.

Figure 25: Damage to handle on a connector

Source: own processing

- **Energy costs** – expenditures on electricity**,**
- **Operating expenses** – Since the batteries are stored in the charging station, it requires frequent, ongoing, regular inspection and servicing once per week from an external company engaged for these tasks, as well as the responsibility of ŠKODA personnel to maintain the charging station clean on an everyday basis. Vehicle utilization costs of the handling equipment are included in the price, which has been agreed upon when signing a contract. If any additional and extra **operating hours** are surpassed, ŠKODA is obligated to pay the over exceeded number of operating hours[2]. The operating hours for tuggers type EZS 570, of which there are three in hall M1B, may be found in appendix F. The goals of the number of operating hours is given for every quarter of

[2] An operating hour is a measurable unit of engine work for the entire machine. It is calculated as the product of the number of engine rotations performed throughout the workday and 60 minutes (1 hour) (Rutteová, 2021).

the year, which should be kept and shall not be exceeded. The example in appendix F shows a perfectly complied restrictions for the year.

- **Leasing payment** of an external company's handling technology – Leasing offers a consistent, predictable bill for usage and eliminates the worry of total replacement expenses in the case of a defect—a company just pays a monthly fee to utilize the equipment for a certain number of hours. Budgeting is considerably easier with a consistent, unchanging monthly cost rather than a huge upfront payment. The cost of purchasing new material handling equipment is much cheaper than the cost of purchasing it outright. Maintenance is included in the contract, so users won't have to find or pay a supplier. After a lease, options such as a buyout or decreased monthly payments towards fair market value are typically provided (Shrader, 2020).
- **Cost for the training of employees** – ŠKODA personnel, whose job description is to drive handling equipment, are required to have proper training on safe manipulation with a double-girder overhead travelling cranes, which is used to uplift the lead-acid battery for recharging.

8.1 Total expenses of the current handling technology

In this subchapter, the author will go into depth on the **current expenditures associated with the usage of lead-acid batteries in handling equipment**. Each employee driving handling equipment has to spend in total around 18–19 minutes of journey time to the charging station, including battery replacement. Consultations with professionals in the field of logistics and the manager responsible for operations in hall M1B were used to conduct calculations on the topic, which took into account personnel expenditures and intern figures. Personnel expenses have been calculated by the formulas (3), (4), (5), (6), (7), where:

T_{ch} – time needed to travel and replacement of the battery (in minutes)
S – number of shifts per day,
T_d – the time per day spent by the operators on changing the current type of battery (in minutes),
W_d – number of working days,

T_w – the time per week spent by the operators on changing the current type of battery (in minutes per week),

W – weeks per one month (in week),

T_{tm} – the time per month spent by the operators on changing the current type of battery (in minutes per month),

H_m – number of hours spent per month on changing batteries (in hour),

Avg_{rate} – the average hourly rate of the operator (in CZK),

T_{cm} – the monthly total expenses spent by the operators on changing the current type of battery (in CZK),

T_{cy} – the yearly total expenses spent by the operators on changing the current type of battery (in CZK per year).

$$T_d = T_{ch} * S \tag{3}$$

T_d = 18.5 * 3 = 55.5 min./day

$$T_w = T_d * W_d \tag{4}$$

T_w = 55.5 * 5 = 277.5 min./week

$$T_{tm} = T_w * W \tag{5}$$

T_{tm} = 277.5 * 4 = 1,110 min./month [3]

$$T_{cm} = H_m * Avg_{rate} \tag{6}$$

T_{cm} = 18.5 * 333 = 6,160.5 CZK/month

$$T_{cy} = T_{cm} * Y \tag{7}$$

T_{cy} = 6,160.5 * 12 = **73,926 CZK/year**

The yearly total expenses, which ŠKODA spends on movement and motion wastes is **73,926 CZK.**

[3] The total time in minutes per month spent by the operators on changing the current type of battery has been converted to hours.

The individual costs of lead-acid battery technology services are depicted in table 4. The necessary data has been provided to the author from an external company, which is providing the services for ŠKODA.

Table 4: Total expenses on one piece of handling equipment with lead-acid battery per year (in CZK)

Lead-acid battery	Tugger (Jungheindrich)	Reach truck (Jungheindrich)	Forklifts 2 t/ 1.6 t/ 1.8 t (Jungheindrich)	Forklifts 4.5 t (Jungheindrich)/ Forklifts 5.5 t (Still)
Charging station costs	900	900	900	900
Personnel expenses for battery replacement	73,926	73,926	73,926	73,926
Demineralized water costs	1,200	2,000	2,000	2,800
Battery repair costs	1,500	1,500	1,500	1,500
Energy costs	4,498	29,040	34,687	91,960
Operating expenses	33,300	58,644	64,284	122,364
Lease payment	72,000	155,880	160,656	263,868
Total	**187,324**	**321,890**	**337,953**	**557,318**

Source: own processing

The charging station costs, personnel costs and battery repair costs are the same for every available type of handling equipment, in view of the fact that all the batteries are stored in one charging station and the expenses are calculated by 1m^2, workers have the same hourly rate, and the repair of batteries is provided by an external company for every type of equipment with the same rate. The expenses of different types of handling equipment varies in demineralized water because the equipment has varied water capacity requirements. The cost of energy is determined by the voltage required for charging the device (the bigger equipment, the higher voltage is needed). Operating expenses are determined by the number of exceeded operating hours, as specified in the contract with the external company that provides handling equipment to ŠKODA. The consumer, ŠKODA, must pay an additional cost for each operating hour that is exceeded, which differs depending on the type of the handling equipment and the specific route on which they have to drive and operate. The lease of each type of handling equipment varies in terms of the external provider's price list.

Yearly total expenses spent on handling equipment with lead-acid batteries is 1,404,485 CZK.

Handling technology with a lead-acid battery goes hand in hand with **special training for safe manipulation with a double-girder overhead** travelling cranes (see appendix G), which is needed for uplifting the whole battery out or into the equipment during the recharging process. It is prohibited to engage in any activities involving the overhead traveling crane if users do not have a license to do so. On the workplace, there might be the possibility of an injury.

ŠKODA selects 20 operators, who will have the opportunity to participate in double-girder overhead travelling cranes manipulation training. The costs include the basic examination course, which lasts one day, and this working day must be paid for to the operator as a regular working day. Every 2 years, the operator has to take a re-examination course which is being paid for by the company, and takes approximately 4 hours, and this time is considered as a working time, which means ŠKODA has to pay for it as well. The expenses which ŠKODA has to invest in trainings of employees, are calculated by the formulas (8), (9), (10), (11) and shown in table 5.

In the following formulas these variables are used:

T_c **– total costs for 1-day training (in CZK per person),**

B_c – expenses for a basic course of double-girder overhead travelling cranes manipulation training (in CZK),

S_1 – 1 working shift (in hours),

Avg_{rate} – the average hourly rate of the operator (in CZK),

T_{c2} **– total costs for every 2-year re-examination course (in CZK per person),**

$S_{1/2}$ – half a day of 1 working shift (in hours),

***T_{c1}* – total costs for 1-year re-examination course (in CZK per person),**

R_{ex} – re-examination course of double-girder overhead travelling cranes manipulation training (in CZK per person),

***A_{c20}* – annual training costs for selected 20 employees (in CZK per year).**

$$T_c = B_{c\,+}\,(Avg_{rate} * S_1) \tag{8}$$

$$\mathrm{T_c} = 2{,}000 + (333 * 8) = 4{,}664 \text{ CZK/person}$$

$$T_{c2} = R_{ex\,+}\,\left(Avg_{rate} * S_{1/2}\right) \tag{9}$$

$$\mathrm{T_{c2}} = 1{,}100 + (333 * 4) = 2{,}432 \text{ CZK/person}$$

$$\mathrm{T_{c1}} = \frac{\mathrm{T_{c2}}}{2} \tag{10}$$

$$\mathrm{T_{c1}} = \frac{2{,}432}{2} = 1{,}216 \text{ CZK/person}$$

$$\mathrm{A_{c20}} = (\mathrm{T_c} * \mathrm{T_{c1}}) * 20 \tag{11}$$

$$\mathrm{A_{c20}} = (4{,}664 + 1{,}216) * 20 = \mathbf{117{,}600\ CZK/year}$$

Table 5: Expenses for double-girder overhead traveling cranes manipulation training for staff per year (in CZK)

Basic course + salary (i.e. T_c)	2,000 + 2,664 [4]	CZK/person
Re-examination course + salary (i.e. T_{c2})	1,100 + 1,332	CZK/person
Annual training costs for 1 employee DTTO	5,880	CZK/year
Annual training costs for selected 20 employees DTTO	**117,600**	**CZK/year**

Source: own processing

[4] the total cost breakdown is in the calculations

Since it is possible that the personnel chosen for training would leave the company during the working year, the author has calculated the expenditures for the basic course on an annual basis. ŠKODA's extra expenses on the training of manipulation with double-girder overhead travelling crane for the selected 20 employees per year is in a total of **117,600 CZK.**

8.2 Total expenses after the implemented proposal

The pricing for introducing a new type of battery is based on prior orders of a similar nature at ŠKODA. The expenses, in general, have decreased once the Li-ion batteries will be applied in comparison to lead-acid batteries. The total expenses of handling equipment with the new type of battery are shown in table 6.

Table 6: Yearly total expenses of handling equipment with Li-ion battery (in CZK)

Li-ion battery	Tugger (Jungheindrich)	Reach truck (Jungheindrich)	Forklifts 2 t/ 1.6 t/ 1.8 t (Jungheindrich)	Forklifts 4.5 t (Jungheindrich)/ Forklifts 5.5 t (Still)
Charging station costs	0	0	0	0
Personnel expenses for battery replacement	0	0	0	0
Demineralized water costs	0	0	0	0
Battery repair costs	0	0	0	0
Energy costs	3,823	24,684	29,484	78,166
Operating expenses	3,828	24,684	29,484	78,168
Lease payment	86,592	203,268	214,656	369,420
Total	**94,243**	**252,636**	**273,624**	**525,754**

Source: own processing

The Li-ion battery does not have an accessible connector for demineralized water, since it is only filled with gel inside and cannot be physically manipulated by employees as it was by lead-acid batteries, where the employees had to spend approximately 18–19 minutes of their working hour for recharging the battery including the drive to the charging station to another hall. The chargers of proposed technology of Li-ion batteries will be located directly in M1B's hall close to the canteen of the employees, to spend time and motion. It is clearly visible from table 6 that the operating expenses will decrease in comparison to lead-acid battery handling equipment shown in table 4. As a result, there will be maximal savings on the demineralized water, personnel expenses, and charging station costs which Li-ion batteries do not require.

The total cost of implementing the proposed technology of Li-ion battery for optimizing the current process per year is a total of **1 146 257 CZK.**

8.3 Total savings and return on investments

The implementation of the proposed system will result in savings. These savings will become apparent after the replacement of the current type of battery in handling technology will be undertaken. The annual saving and return on investments by implementing the proposed type of Li-ion battery has been calculated by the formula (12), where:

T_{as} – total annual savings (in CZK),
T_c – the difference of the total costs of each handling equipment with lead-acid and li-ion battery (in CZK),
T_a – total amount of the type of handling equipment (in CZK).

$$T_{as} = T_c \ * \ T_a \qquad (12)$$

T_{as} (tugger) = 93,081 * 7
T_{as} (tugger) = 651,567 CZK

T_{as} (reach truck) = 69,254 * 4
T_{as} (reach truck) = 277,016 CZK

$$T_{as}\text{(forklifts 2 t/1.6 t/ 1.8 t)} = 64{,}329 * 12$$

$$T_{as}\text{ (forklifts 2 t/1.6 t/ 1.8 t)} = 771{,}948\text{ CZK}$$

$$T_{as}\text{ (forklifts 4.5 t/ 5.5 t)} = 31{,}564 * 9$$

$$T_{as}\text{ (forklifts 4.5 t/ 5.5 t)} = 284{,}076\text{ CZK}$$

The results of every type of handling equipment for hall M1B is multiplied with the number of vehicles for each handling equipment are depicted in table 7.

Table 7: Total annual savings for one piece of every type of handling equipment by implementing Li-ion battery (in CZK)

	Tugger (Jungheindrich)	Reach truck (Jungheindrich)	Forklifts 2 t/ 1.6 t/ 1.8 t (Jungheindrich)	Forklifts 4.5 t (Jungheindrich)/ Forklifts 5.5 t (Still)
Annual savings	**651,567**	**277,016**	**771,948**	**284,076**

Source: own processing

After the calculation of the whole amount of expenses which has been invested into handling technology with lead-acid batteries and having it compared to the proposal of replacing the current type of battery with a new Li-ion battery of **1 984 607 CZK** including the reduction of costs for extra training for manipulation with double-girder overhead traveling crane of **117 600 CZK**, the author conducted the total annual saving in a total of **2,102,207 CZK per year**.

Conclusion

The concept of lean business management originated in the automotive industry, but due to its universal nature, this approach may be implemented in other industries where lean management can also assist to optimize company operations and minimize waste. The primary reason for implementing lean management in a company is the apparent advantage it provides in minimizing those operations in business processes that do not add any value that the customer requires. Therefore, it is employed in logistics, manufacturing, and non-manufacturing enterprises, as well as in public governmental institutions. It is one of the most sought-after modern company management concepts that will have a huge impact on business entities in the future due to its innovative and productive character.

In the diploma thesis, which elaborates on the topic "Lean Logistics in axle production", the author devoted herself to research to reduce waste in logistics processes. The research has been undertaken in the company ŠKODA Auto a.s. for the department of material management (axle production), whose main operation is the production of automotive components. The technologies highlighted were aimed at the field of logistics and the importance of selected technologies for the competitiveness of the company in the market was mentioned. The aim of this diploma thesis was to analyze the current state of handling technology utilization and identify its critical points, further outline necessary measures to eliminate these critical points and economically evaluate the recommended adjustments.

The introductory part of the diploma thesis has been devoted to the literature review, which was the theoretical foundation in lean management and logistics, and for implementation of the information in the practical part. Lean logistics, waste in business operations, warehousing, and others were mentioned in this part.

The practical part of this diploma thesis was based mainly on the author's actual work in the ŠKODA company, as well as the processing of the company's internal resources. Furthermore, data were gathered through discussions and meetings with internal corporate personnel, including the thesis consultant. In the practical part of the thesis, the aim was to propose a specific type of battery for handling technology in the automotive industry, which would save space and reduce the motion and movement of handling equipment operators in terms of time and expenditures. The suggestion of implementation of the author is achieved by replacing the battery in logistics processes to improve and save on the processes in the automotive industry. The proposal included the workforce that is tied to the operation of the current process.

The proposal concerned the replacement of the current type of lead-acid battery in handling technology with a Li-ion battery. This type of battery is more powerful and safe to handle. It is feasible to significantly save time, motion, and expenses, as well as prevent employee accidents in logistics, with the aid of the suggested type of selected technology.

With the replacement of battery types emerged a concept for a prospective parking lot with Li-ion battery chargers and handling equipment. This results in optimization and significant savings. The proposal in the diploma thesis has a short payback period, which in this case would be in 1 year after implementation. The proposal was assessed economically, where the annual savings would be a total of 2,102,207 CZK.

References

ACHAHCHAH, Mohamed, 2018. *Lean Transportation Management: Using Logistics as a Strategic Differentiator*. New York: Routledge. ISBN 9780429490101.

BÁNYAI, Tamás, Béla ILLÉS, Miklós GUBÁN, Ákos GUBÁN, Fabian SCHENK and Ágota BÁNYAI, 2019. Optimization of Just-In-Sequence Supply: A Flower Pollination Algorithm-Based Approach. *Sustainability* [online]. 11(14) [Accessed 2022-05-03]. Available at: doi:10.3390/su11143850

BAUDIN, Michael, 2004. *Lean logistics: the nuts and bolts of delivering materials and goods*. New York: Productivity Press. ISBN 1563272962.

BOWERSOX, Donald J., David J. CLOSS, M. Bixby COOPPER and John C. BOWERSOX, ed., 2013. *Supply chain logistics management.* 4. ed., internat. ed. New York: McGraw-Hill. ISBN 9780071326216.

BRADLEY, James R., 2012. *Improving Business Performance With Lean*. New York: Business Expert Press. The supply and operations management collection. ISBN 9781606492642.

CFI EDUCATION, 2021. Logistics - Definition, Role, Inbound and Outbound Logistics. In: *Corporate Finance Institute* [online]. Vancouver: CFI Education [Accessed 2021-12-28]. Available at: https://corporatefinanceinstitute.com/resources/knowledge/other/logistics/

CHARRON, Rich, H. et al., 2015. *The Lean Management Systems Handbook*. Boca Raton, FL: Productivity Press. ISBN 139781466564350.

CHIARINI, Andrea, 2012. *Lean Organization: from the Tools of the Toyota Production* System to Lean Office. Milano: Springer Milano. ISBN 9788847055971.

ČTK, 2021. Ecobat: Recyklace lithia z baterií se teď nevyplatí, bude třeba i růst kapacit. In: *České noviny | ČeskéNoviny.cz* [online] [Accessed 2022-04-22]. Available at: https://www.ceskenoviny.cz/zpravy/ecobat-recyklace-lithia-z-baterii-se-ted-nevyplati-bude-treba-i-rust-kapacit/2072212

DOLAN, Antonín, 2018. *Logistika: Interní učební text* [online]. České Budějovice. Jihočeská univerzita v Českých Budějovicích. Available at: http://kzt.zf.jcu.cz/wp-content/uploads/2018/06/logistika.pdf

DVOŘÁK, 2022. *Logistika PKL/22 – Výroba Náprav*. In: ŠKODA AUTO a.s., Unpublished internal company document.

EATON, Mark, 2013. *The Lean Practitioner's Handbooks*. London: Kogan Page. ISBN 9780749467739.

ECOBAT, 2022. Recycling. In: *Ecobat | Resources Essential to Modern Life* [online]. Irving: Ecobat [Accessed 2022-01-29]. Available at: https://ecobat.com/sustainability/recycling/

EPRIN, 2020. Zavedení čárového kódu. In: *Eprin.cz* [online]. [Accessed January 29, 2022]. Available at: https://www.eprin.cz/carove-kody.html

FATHI, Masood, Amir NOURMOHAMMADI, Morteza GHOBAKHLOO and Milad YOUSEFI, 2020. Production Sustainability via Supermarket Location Optimization in Assembly Lines. In: *Sustainability* [online]. **12**(11), 4728 [Accessed 2022-05-03]. ISSN 2071-1050. Available at: https://www.proquest.com/docview/2412676546/93F05465BCD4D85PQ/4?accountid=17116

FLASH BATTERY, 2017. Advantages of lithium batteries vs lead-acid batteries. In: *Flash Battery* [online]. Sant'Ilario d'Enza: Flash Battery [Accessed 2022-02-14]. Available at: https://www.flashbattery.tech/en/why-switch-from-lead-acid-battery-to-lithium-battery/

GROS, Ivan. et al., 2016. *Velká kniha logistiky*. Praha: Vysoká škola chemicko-technologická v Praze. ISBN 9788070809525.

HUA, Yang, Sida ZHOU, Yi HUANG, Xinhua LIU, Heping LING, Xinan ZHOU, Cheng ZHANG and Shichun YANG, 2020. Sustainable value chain of retired lithium-ion batteries for electric vehicles. In: *Journal of Power Sources* [online]. **478**, 228753 [Accessed 2022-05-03]. ISSN 0378-7753. Available at: https://doi.org/10.1016/j.jpowsour.2020.228753.

JENKINS, Abby, 2020. Guide to Inbound and Outbound Logistics: Processes, Differences and How to Optimize. In: *Business Software, Business Management Software | NetSuite* [online]. Austin: Oracle [Accessed 2021-01-28]. Available at: https://www.netsuite.com/portal/resource/articles/inventory-management/inbound-outbound-logistics.shtml

JUNGHEINRICH AG, 2021. JT Energy Systems staví úložiště energie z recyklovaných Li-ion baterií. In: *Jungheinrich AG | Komplexní řešení pro intralogistiku* [online]. [Accessed 2021-12-28]. Available at: https://www.jungheinrich.cz/blog/jt-energy-systems-1098234?utm_source=82268-JH%20interni%20novinky&utm_medium=email&utm_term=9278958540&utm_content=ZJISTIT%20V%C3%8DCE%C2%A0%20%C2%A0%20%E2%86%92&utm_campaign=Aktu%C3%A1ln%C3%AD--20220125

JUNGHEINRICH, 2022. *Přehled nabíječů a nabíjecí časy.* Unpublished internal company document.

JUROVÁ, Marie. et al., 2013. *Výrobní procesy řízení logistikou*. Brno: BizBooks. ISBN 9788026500599.

KAISER + KRAF, 2022. Axelent – Systém dělicích stěn X-STORE 2.0, stěnový prvek. In: *Kaise + Kraf* [online]. [Accessed 2022-04-18]. Available at: https://www.kaiserkraft.cz/stavby-pristresky/prvky-mrizkovych-delicich-sten/system-delicich-sten-x-store-2-0-stenovy-prvek/vyska-1100-mm/p/M11588839/?articleNumber=650184&utm_content=Cabins-/-shelters%3EMesh-storage-wall-elements&utm_term=650184&customerType=B2C&PC=&storefront=current&infinity=ict2~net~gaw~ar~514771829949~kw~~mt~~cmp~12759784779~ag~126580006048&gclid=Cj0KCQjwpImTBhCmARIsAKr58cz5fVKayKFN0B5KLQT9fRsg8B8XaxwuciPa2VpKnaGeNT82gHb4bTAaAjh8EALw_wcB

KAMPF, Rudolf, Vojtěch STEHEL, Daniel KUČERKA, Ján KMEC, Liu XIQUAN, Li BIHAN and Cui WEI, 2017. *Logistics of production processes*. České Budějovice: The Institute of Technology and Business in České Budějovice. University textbook. ISBN 9788074681158.

KING, Peter L. & KING, Jennifer S., 2015. *Value Stream Mapping for the Process Industries: Creating a Roadmap for Lean Transformation*. Boca Raton, FL: CRC Press. ISBN 9781482247695.

LIKER, Jeffrey K. & MEIER, David, 2006. *The Toyota Way Fieldbook: A Practical Guide For Implementing Toyota's 4Ps*. United States of America: The McGraw-Hill Companies. ISBN 9780071448932.

METAYE, Romain, 2022. Lead-acid vs Lithium-Ion (10 Key Differences). In: *Climatebiz* [online]. [Accessed 2022-02-14]. Available at: https://climatebiz.com/lead-acid-vs-lithium-ion/#4--lead-acid-vs-lithium-ion-which-is-more-durable

MYERSON, Paul, 2012. *Lean Supply Chain & Logistics Management*. The McGraw-Hill Companies. ISBN 9780071766265.

OBARA, Samuel & WILBURN, Darril, 2012. *Toyota by Toyota: Reflections from the Inside Leaders on the Techniques That Revolutionized the Industry*. New York: Productivity Press. ISBN 9781439880753.

OHNO, Taiichi, 2013. *Taiichi Ohno's Workplace Management*. London: McGraw-Hill. ISBN 9780071808019.

PAKSOY, Turan, Çiğdem KOÇHAN and Sadia Samar ALI, ed., 2021. *Logistics 4.0: Digital Transformation of Supply Chain Management*. Florida: Taylor & Francis Group. ISBN 9780367340032.

PILOT GROUP, 2022. Lithium-ion battery vs lead-acid battery. In: *Pilot group* [online]. [Accessed 2022-02-14]. Available at: https://www.thepilotgroup.co.uk/lithium-ion-battery-vs-lead-acid-battery/#:~:text=Typically%20for%20lithium%20ion%20batteries,be%20stored%20by%20the%20battery.

PRAŽANOVÁ, Anna., KNAP, Václav. and STROE, Daniel-Ioan, 2022. Literature Review, Recycling of Lithium-Ion Batteries from Electric Vehicles, Part I: Recycling Technology. In: *Energies* [online]. **15**(3), 1086 [Accessed 2022-05-03]. ISSN 1996-1073. ProQuest Central; ProQuest One Academic; Publicly Available Content Database. Available at: http://dx.doi.org/10.3390/en15031086.

RUTTEOVÁ, Lenka, 2021. Jak se počítá motohodina. In: *Skrblík* [online]. [Accessed 2022-01-04]. Available at: https://www.skrblik.cz/navod/jak-se-pocita-motohodina/

SAYER, Natalie J., 2012. *Lean For Dummies*. John Wiley. ISBN 1118117565.

SHRADER, Lindsey, 2020. Should you buy, rent, or lease your MHE equipment. In: *Kenco* [online]. [Accessed April 1, 2022]. Available at: https://blog.kencogroup.com/should-you-buy-rent-or-lease-your-mhe-equipment

SHEVTSHENKO, Eduard, Viktoria BASHKITE, Meysam MALEKI and Yan WANG, 2012. Sustainable design of material handling equipment: A win-win approach for manufacturers and customers. In: *Mechanika* [online]. **18**(5), 561–568. Available at: doi:10.5755/j01.mech.18.5.2703

SIMPLELIFT, 2019. Olověné vs Li-Ion baterie. In: SimpleLift. *Simple Lift s.r.o. - prodej a servis manipulační techniky* [online]. Brno: SimpleLift [Accessed 2022-01-22]. Available at: https://simplelift.cz/olovene-vs-li-ion-baterie/

ŠKODA Auto a. s., 2021. *ŠKODA AUTO Company presentation*. Unpublished internal company document.

ŠKODA Auto a.s., 2022. *Organizační struktura.* Unpublished internal company webpage.

SVOZILOVÁ, Alena, 2011. *Zlepšování podnikových procesů*. Praha: Grada Publishing. ISBN 9788024739380.

TORNESE, Fabiana.; ANTE, Giorgi., GNOMI, Maria. G., 2017. *Analyzing the transition from just-in-time to just-in-sequence: a simulation based approach from the automotive sector.* In: *Research Gate* [online]. [Accessed 2022-04-20]. Available at: https://www.researchgate.net/profile/Fabiana-Tornese/publication/319876713_Analyzing_the_transition_from_just-in-time_to_just-in-sequence_a_simulation_based_approach_from_the_automotive_sector/links/59bf893eaca272aff2e1c1bc/Analyzing-the-transition-from-just-in-time-to-just-in-sequence-a-simulation-based-approach-from-the-automotive-sector.pdf

TURKOVÁ, Jana, 2017. Zajištění sběru a třídění baterií, galvanickách článků, akumulátorů. In: *ŠKODA Auto a.s. manual*. Unpublished internal company document.

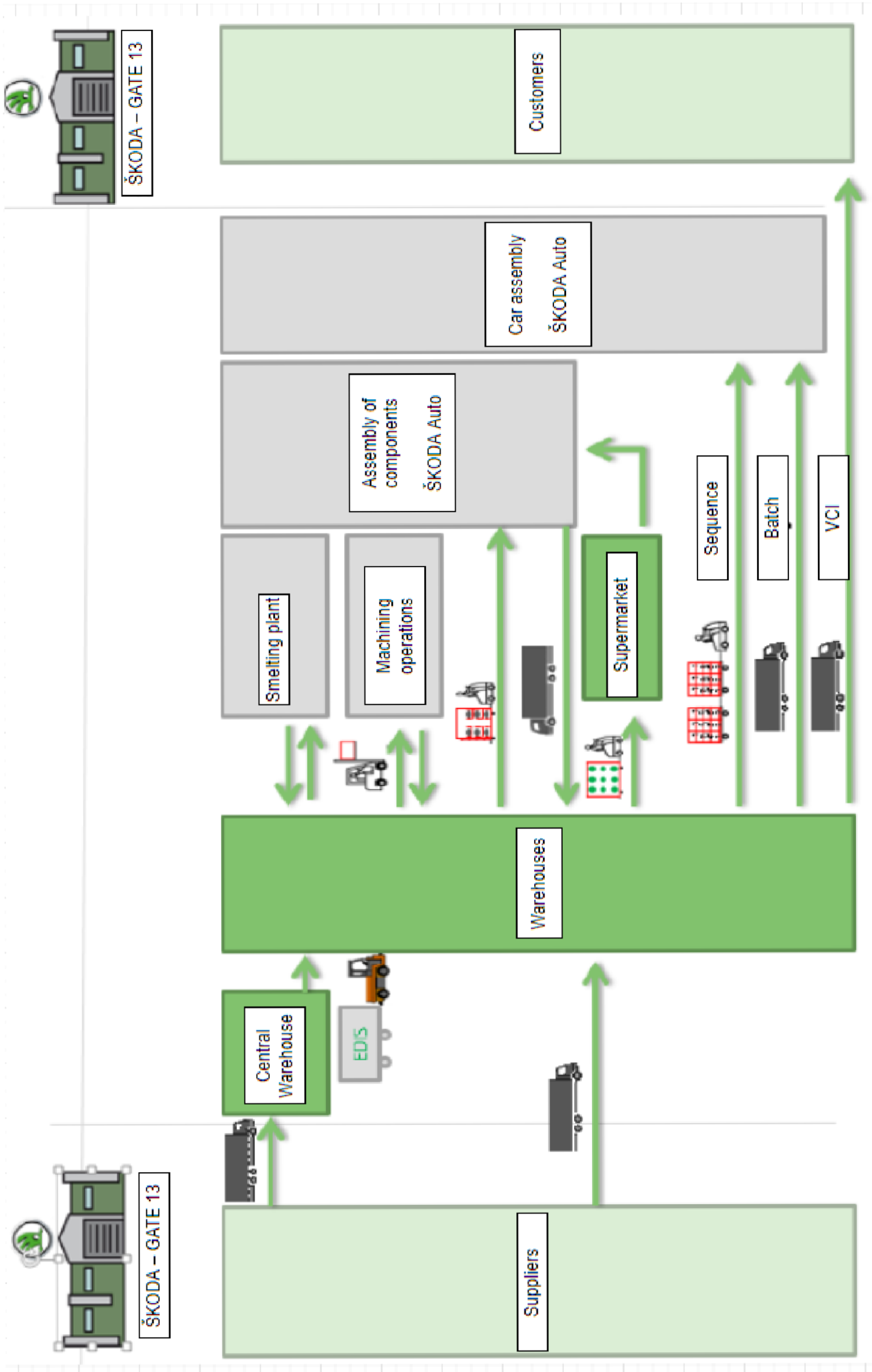
TOYOTA MATERIAL HANDLING CZ, 2020. Zájem o lionky strmě roste: nová modulární technologie od Toyoty rozšiřuje oblasti použití. In: *T-way: magazín o logistice, skladování a manipulační technice.* (2), 22-24. ISSN 1803-6880.

TOYOTA MATERIAL HANDLING CZ, 2021. Poptávky i objednávky AGV vozíků Toyota Autopilot nabírají na obrátkách. In: *T-way, 2021. Magazín o logistice, skladování a manipulační technice*. (2) 9-10. ISSN 1803-6880.

WANG, Shuli., 2022. Multi-Angle Analysis of Electric Vehicles Battery Recycling and Utilization. In: *IOP Conference Series. Earth and Environmental Science* [online]. [Accessed April 20, 2021]. 04, vol. 1011, no. 1, pp. 012027 ProQuest Central; ProQuest One Academic; Publicly Available Content Database. ISSN 17551307. Available at: http://dx.doi.org/10.1088/1755-1315/1011/1/012027.

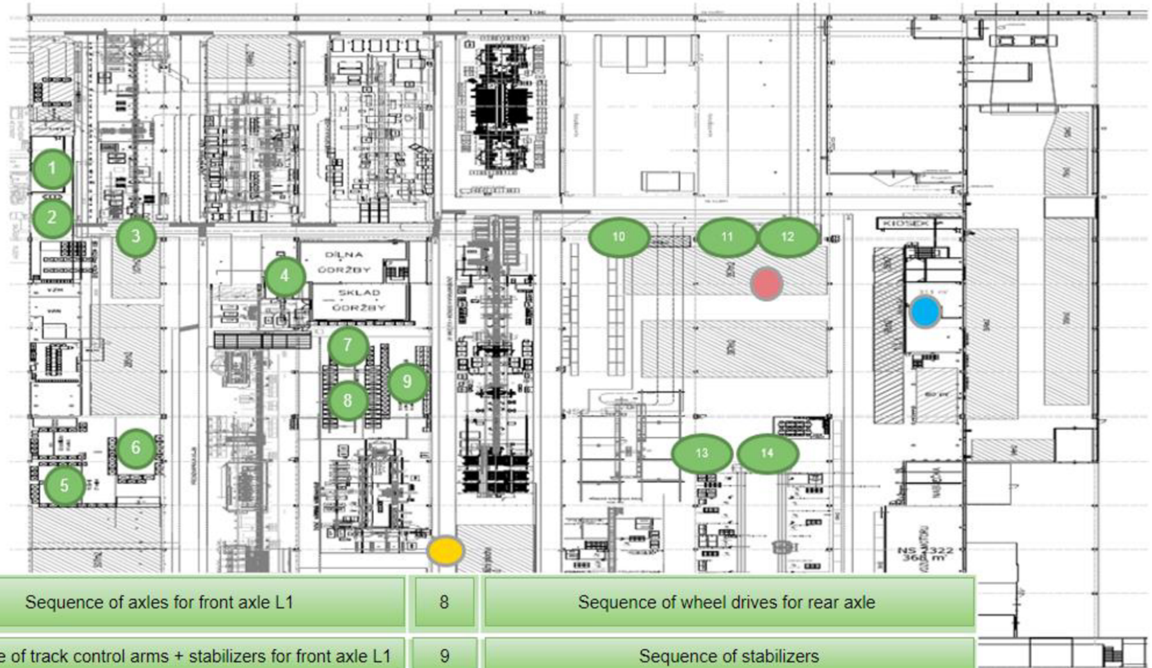
List of Appendices

Appendix A: Material flow of components in PKL



Source: ŠKODA (2022)

Appendix B: Visualization of sequential workplaces

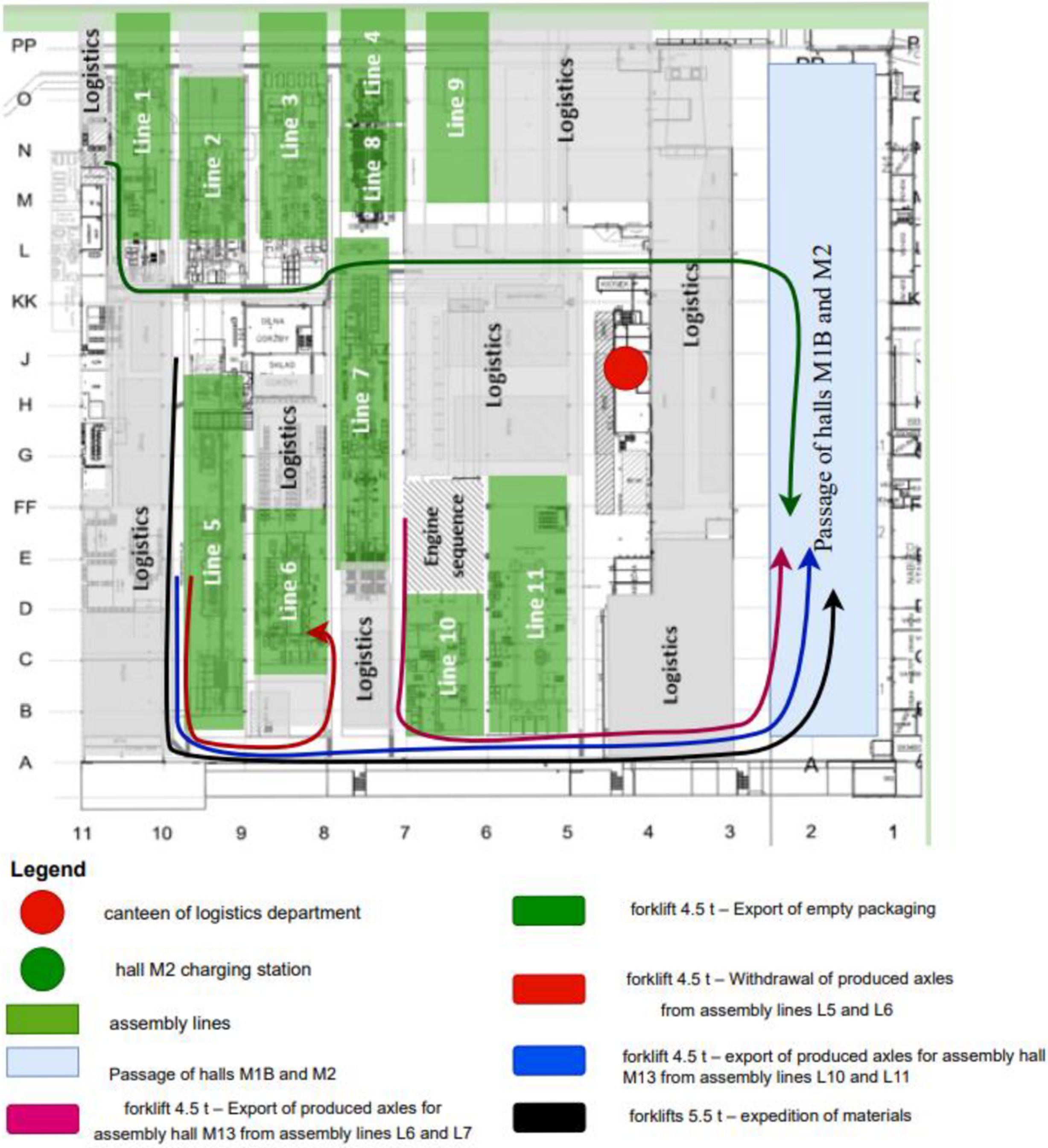


1	Sequence of axles for front axle L1	8	Sequence of wheel drives for rear axle
2	Sequence of track control arms + stabilizers for front axle L1	9	Sequence of stabilizers
3	Sequence of power steering for front axle L2	10	Sequence of shock absorbers for L4
4	Sequence of inter-axle differential clutch + cardan shafts for rear axle	11	Sequence of suspention springs
5	Sequence of axle for rear axle	12	Sequence of axles for rear axle L9
6	Sequence of power steering for front axle L5	13	Sequence of power steering for MEB L10
7	Sequence of track control arm for front axle L5	14	Sequence of stabilizators for MEB L11

- office of axle logistics
- supermarket of axle logistics
- main entrance to the axle production

Source: own processing

Appendix C: Layout of routes of handling equipment



Source: own processing

Appendix D: Overview of chargers and charging times for handling equipment in hall M1B

Voltage	Charger	Type of charger plug	Maximal electric current (A) for 1 phase	Consumption (kW)	Necessary electrical fuses	40 Ah		110 Ah	
						50%	100%	50%	100%
24 V	Integrated charger 35 A		5.3	0.8		34	69	94	189
	SLH 040 i	A Schuko 230V / 16A	6	1.3	1 x 16A	30	80	-	-
	24/100 SLH 090i	A Schuko 230V / 16A	14.5	3.2	1 x 16A	-	-	33	66

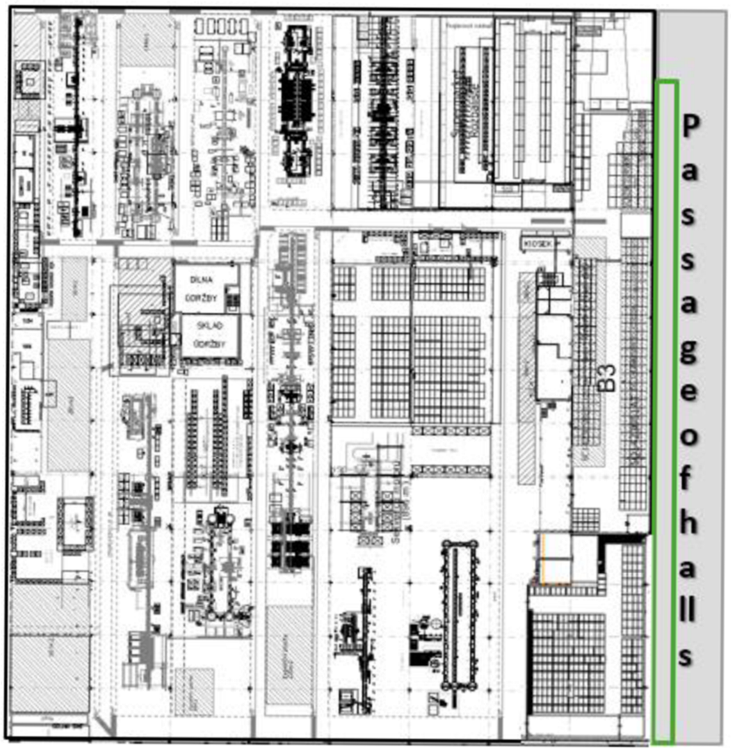
Voltage	Charger	Type of charger plug	Maximal electric current (A) for 1 phase	Consumption (kW)	Necessary electrical fuses	130 Ah		208 Ah		260 Ah		390 Ah	
						50%	100%	50%	100%	50%	100%	50%	100%
24 V	24/50 SLH 300i	A Schuko 230V / 16A	7.8	1.6	1 x 16A	78	156	125	250	156	312	234	468
	24/100 SLH 300i	A Schuko 230V / 16A	15.6	3.2	1 x 16A	39	78	62	125	78	156	117	234
	24/150 SLH 300i	CEE C1 400V / 16A	7.8	5.4	3 x 16A	30	60	42	83	52	104	78	156
	24/200 SLH 300i	CEE C1 400V / 16A	15.6	7.1	3 x 16A	30	60	31	62	39	78	59	117
	24/260 SLH 300i	CEE C1 400V / 16A	15.6	9.4	3 x 16A	30	60	30	60	30	60	45	90
	24/300 SLH 300i	CEE C1 400V / 16A	15.6	10.7	3 x 16A	30	60	30	60	30	60	39	78

Voltage	Charger	Type of charger plug	Maximal electric current (A) for 1 phase	Consumption (kW)	Necessary electrical fuses	360 Ah	156 Ah		260 Ah		364 Ah		390 Ah		416 Ah		520 Ah	
						100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%	50%	100%
48 V	48/100 SLH 300i	CEE C1 400V /	15,6 / 10,3	7.1	3 x 16A	-	47	94	78	156	109	218	117	234	125	250	156	312
	48/150 SLH 300i	CEE C1 400V /	15,6 / 15,4	10.7	3 x 16A	-	31	62	52	104	73	146	78	156	83	166	104	208
	48/200 SLH 300i	CEE C2 400V /	31,2 / 20,5	14.2	3 x 32A	-	30	60	39	78	55	109	59	117	62	125	78	156
	48/260 SLH 300i	CEE C2 400V /	31,2 / 25,7	17.8	3 x 32A	-	30	60	30	60	42	84	45	90	48	96	60	120
	48/300 SLH 300i	CEE C2 400V /	31,2/ 30,8	21.3	3 x 32A	-	30	60	30	60	36	73	39	78	42	83	52	104
	Integrated charger (ETV	CEE C1 400V /	7.2	3 x 16A		90	-	-	-	-	-	-	-	-	-	-	-	-

Voltage	Charger	Type of charger plug	Maximal electric current (A) for 1 phase	Consumption (kW)	Necessary electrical fuses	500 Ah	
						50%	100%
80 V	80/160 SLH 090i	CEE C2 400V / 32A	30.1	17.3	3 x 32A	88	176
	80/220 SLH 090i	CEE C3 400V / 63A	44.3	23.8	C3	68	136
	80/260 SLH 090i	CEE C3 400V / 63A	45.8	28.1	C3	58	115
	80/290 SLH 090i	CEE C3 400V / 63A	45.4	31.3	C3	52	103

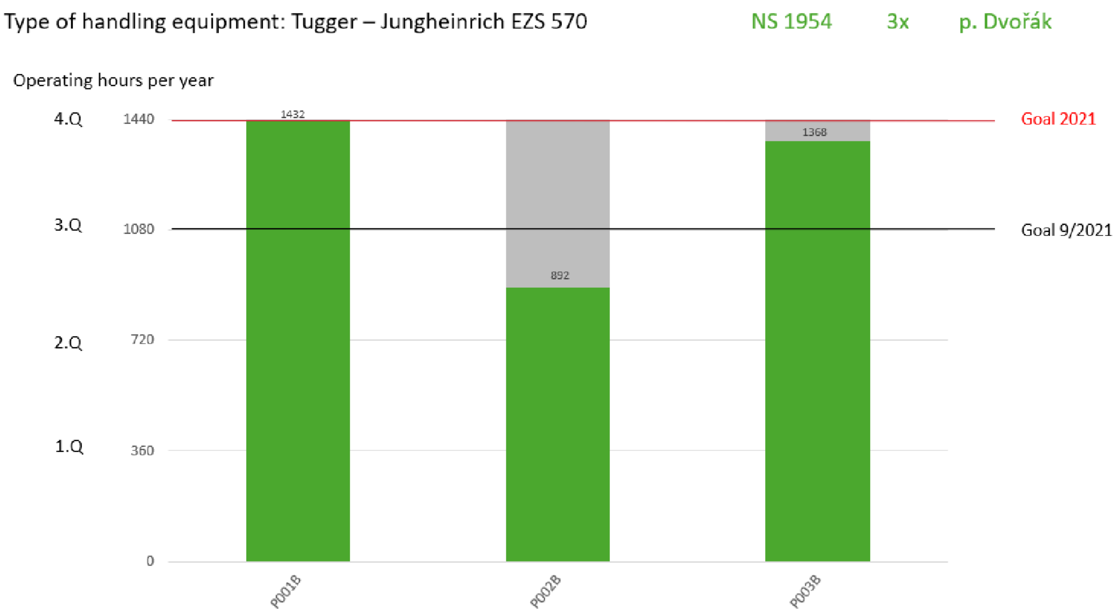
Source: Jungheinrich (2022)

Appendix E: Roofing of passage of halls between M1B and M2



Source: own processing

Appendix F: Operating hours for handling equipment (Tugger and forklift 4.5t)



Type of handling equipment	January	February	March	April	May	June	July	August	September	October	November	December
	Operating hours (in mth)											
Forklift 4.5 t/ S070C	423	342	413	395	472	348	268	162	216	151	392	357
Forklift 4.5 t/ S071C	416	370	357	355	332	286	209	101	181	138	165	291
Forklift 4.5 t/ S072C	398	352	386	387	436	299	198	140	201	140	338	327
Forklift 4.5 t/ S073C	382	265	392	354	421	311	218	143	185	121	358	297

Source: own processing

Appendix G: Double-girder overhead travelling crane uplifting the lead-acid battery

Source: own processing