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METHODOLOGY PROPOSAL FOR STORAGE RATIONALIZATION BY IMPLEMENTING PRINCIPLES OF INDUSTRY 4.0. IN A TECHNOLOGY-DRIVEN WAREHOUSE

Summary

The paper deals with storage rationalization and brings forward a proposal of a methodology for the rationalization of storage systems in warehouses of industrial companies. The methodology emphasizes the new concept of Warehouse 4.0, including Industry 4.0 warehouse applications in general. The first part of the paper starts with the theoretical background and a description of logistics, Logistics 4.0, warehouse systems, Warehouse 4.0 and modern approaches linked to Industry 4.0 that can be implemented in logistics. Then, the factors influencing the effectiveness of the warehouse are summarized – this is an original summary based on the available literature and other sources. After this, storage rationalization and the related costs are described. The main subject of the paper is explained in the second part of the paper, which concentrates on the proposal of a methodology for storage rationalization of warehouses in industrial companies. The individual steps in the storage rationalization are described. The purpose of the paper is to share information, firstly, about the summarised factors influencing the effectiveness of a warehouse and, secondly, about the methodology proposal itself. This information may inspire other research institutions to consider aspects of this subject matter, which could be otherwise overlooked.

Key words: *logistics, warehouse, rationalization, Warehouse 4.0, Industry 4.0*

1. Introduction

Internal logistics, including activities associated with ensuring the availability of materials in production and the preparation of the delivery to customers, forms a significant part of the activities of every manufacturing company and significantly affects both the cost and revenue of the corporate economy. The constant expansion of the product range, the pressure to reduce production times and optimize operating costs force companies to innovate established internal logistics processes in order to be able to respond to changes in both the production environment and the market in a more flexible way. However, it is essential to have an overview of the activities when it comes to internal logistics.

Production and internal logistics focus on the solution and optimization of material flows, the creation of handling systems, the use of space and working conditions and other tasks related to the product. Based on the work by Heinrich [1], it is possible to list the main key areas of internal logistics, which are further divided into subgroups. The primary operational functions of internal logistics are material handling, warehousing, internal transport within the company (warehouse, production sector, etc.), picking and packaging.

One of the critical areas is the warehouse space, where the issues of storage, the creation of optimal storage locations, the installation of suitable storage technologies, etc. are addressed.

Warehousing helps a company to improve the quality of the services it provides, thereby achieving a higher level of customer satisfaction while at the same time reducing storage costs. Cost savings can be achieved mainly by modifying the storage function of warehouses, the possibility of postponing the end operations to ordering goods by the customer or storing seasonal items or sending bulk orders. All this will enable the company to use the storage capacity evenly. Thus, storage contributes to improving customer service by increasing and facilitating product availability [2]

There are three basic storage functions. These are functions related to the transfer of products, the storage of products and the transmission of information. [3,4]

Transfer of products refers to

- receiving products – unloading, unpacking, updating inventory, checking products status, checking documentation,
- deposition of products – transfer of products to the warehouse, storage,
- completion of products according to orders – picking products according to orders from customers,
- reloading – moving products from receipt to shipping – cross-docking (no storage required),
- shipment of goods – packing products according to customer requirements, inspection, loading products on a means of transport, adjustment of inventory.

Storage of products refers to temporary storage, i.e. storage of products necessary for replenishment of basic stocks, and time-limited storage, the so-called ‘overstock’. The reason for the latter type of storage may be seasonality, surge in demand, product modification or special purchasing conditions.

Transmission of information refers to stock status information, order picking and ordering information, order status etc.

While in the previous stage of digitization computers and robots were introduced to industry, the fourth Industrial Revolution connected them and taught them to communicate. The key to the concept of smart factories is the ability to interconnect all operating machines. Mutually communicating robots, ancillary equipment, production equipment and products make autonomous decisions in real time. Automated logistics equipment in all areas of internal logistics (material handling, storage and packaging) uses autonomous logistics elements and robots and adapts to production needs. [5]

The concept of Industry 4.0 has, of course, a broad scope and a significant impact on the areas of internal logistics, or the areas of storage described below. The vision of smart logistics is to connect warehousing systems, transport technologies and planning software into one interconnected network that can automatically create and modify logistics processes concerning other links in the production chain.

The technologies and principles of Industry 4.0 will be implemented in the field of internal logistics as described by Wang [6], where the main technologies are, for example, big data, smart sensors, radio-frequency identification (RFID), Internet of Things (IoT), Internet of Services (IoS), smart collaborative robots, autonomous automated guided vehicles (AGVs) and drones and GPS navigation systems for handling active devices. Some systems can be designed so ingeniously that there is virtually no need for human intervention and production is fully automated. However, we often encounter 'collaborative environments', where machines and people work together to create a synergistic effect.

Warehousing entails many sub-activities, such as receiving material, storing material in an assigned storage location, picking material for production (picking), or assembling ordered parts (kitting), ensuring the process of dispatching orders, including packaging and other activities.

So far, these areas have been heavily dependent on the deployment of manpower in the form of warehouse workers because the collection and handling of warehouse items, especially in the case of very diverse objects, has not been very suitable for robots, which are ideal for routine, standardized operations. The most common reasons for modernization and automation of warehouse management are excess inventory, many different types of goods and complicated access to information (consumption records, complaints, returns, etc.) and unproductive time in the form of searching for goods by warehouse workers. A higher degree of automation also helps companies address labour shortages while better managing seasonal fluctuations. The new generation of devices will be aimed at the type of robots with humanoid elements, the so called "cobots", that will naturally collaborate with human workers. Drones represent a separate development branch of robotics. [7]

So far, warehouse automation has been mainly concerned with handling pallets and packages. However, robotic systems can already handle even more complex operations. In addition, there has been a significant reduction in the overall cost of robotics - meaning that previously costly automated solutions or even robots for integration into lines and systems can be now afforded by companies. Implementing robots capable of understanding voice and other instructions and robots that move, respond to their environment and perform precise tasks will be part of the Warehouse 4.0 concept. [8]

Elimination of human factor interference is the highest form of warehouse management automation through closed unattended warehouse systems. Such a fully autonomous warehouse requires tailor-made equipment, in addition to automatic storage - rack stackers and robots - as well as a fleet of AGVs or drones.

The proposed research methodology allows the use and rationalization of current needs or specific challenges a company is facing. The methodology is not focused on a specific size of a company or its character and retains a certain degree of generality and versatility. However, due to the conditions in the Czech Republic and the focus of the authors in terms of research and use, the methodology is designed for industrial enterprises in the field of engineering and the automotive industry, where these enterprises have a significant share on the local market.

Regarding the possibilities of implementing the elements, principles and technologies of Industry 4.0 in the field of internal logistics, it is not the size of the company that matters, but its current state and level of readiness for the implementation of this concept. The proposed methodology includes also a model of readiness, which assesses the readiness of the company and determines its current level in the field of internal logistics or warehousing. Fulfilling the vision of a company in which machines and systems are largely autonomously diagnosed, configured and optimized in order to achieve higher productivity is realistic for every company that sets out on this path.

2. Literature review

According to [6], Logistics 4.0 is 'a collective terminology for technologies and concepts of the organization's value chain'. The crucial task is to implement all the logistics processes within the organization, while maintaining all Warehouse 4.0 principles. The evolution of logistics has been mainly based on specific changes (innovations):

- mechanization of transportation at the end of the 19th century and beginning of the 20^{th} century (Logistics 1.0),
- automation of the goods handling system in the 1960s (Logistics 2.0),
- innovation in management systems logistics (Logistics 3.0) in the 1980s,
- Internet of Things and Internet of Services (IoT, IoS) and Big Data that have implications for logistics (Logistics 4.0).

Workforce savings and standardization of supply chain management are, according to [9], the main objectives of Logistics 4.0. Supply chain management can be defined as a large network where all parts of the supply chain are involved – from suppliers to end customers. The Internet is crucial here as logistics activities are monitored, accompanied and solved based on the information from inter-company or extra-net sources. Also, a platform accessible by all chain users is needed here.

Let us consider Warehouse 4.0, part of the Logistics 4.0 and smart supply chain management in more detail. In [9], the smart warehouse is defined as 'an automated, unmanned, and paperless warehouse when conducting the operations of pickup, delivery, and bookkeeping'. Using intelligent management that is adopted and implemented correctly based on the Industry 4.0 principles, in combination with hardware and software technologies (hereinafter we will discuss concrete solutions) leads to changes in warehousing systems already in use. This is called Warehouse 4.0. and this is going to make some changes in already adopted warehousing management systems in companies. Also, the Internet of Things technology and specific applications in warehouse operations such as RFID technology, management and control technology and sensor technology are introduced in [10]. Adopting this system requires simultaneous treatment of production and warehouse infrastructure, transport-warehouse technology and warehouse management systems. Warehouse 4.0 represents a new area of storing and retrieving goods by using shuttle-based storage and retrieval systems instead of fixed crane automated warehouses. [11]

The goal is to reduce warehousing costs to a minimum. In some cases, we try to eliminate them completely. This is because it is possible to process orders from consumers and suppliers at the same time. According to [6], transforming warehouse management into Warehouse 4.0 requires Industry 4.0 components implemented into technical logistics.

One of the core components of Warehouse 4.0 is automation. Automation means here that a computer collects technology-based data. In the context of Warehouse 4.0 the automation technology is applied in the form of:

- bar-code technology (also scanning),
- smart-card technology,
- tablets,
- radio frequency identification (RFID),
- real-time locating systems – to automatically identify and track the location of goods,
- smart scanning technology (smart sensing) – to detect the condition of goods or environmental changes that occur around the item,
- AGV will be integrated into the Internet of Things warehouse, and this is related to warehouse/truck loading automation, by using shuttle-based storage and retrieval systems.

Also, there are some limitations to using new technologies. The 2016 report from Zebra Technologies [12] states that 'the retail, wholesale, transportation and logistics sectors are transitioning to "best-of-breed" warehouse management systems that take automatization to new heights – from equipping workers with mobile devices that increase the speed and accuracy of order picking to the roll-out of radio frequency identification technology (RFID) for real-time inventory visibility'. But several concerns still exist, and scepticism remains (cost savings or a positive ROI). [13]

2.1 Using a Cyber-Physical System (CPS) when transforming from traditional warehouses to warehouse 4.0.

Using a CPS is the most effective way to transform traditional warehouses into smart ones (Warehouse 4.0). CPSs create a virtual copy of the real world (workplaces, components, industry processes). Thus, we know the status of each component and make decisions in real time even before the actual process is running. The CPS can combine virtual and physical worlds so they can communicate and interact through smart objects. This also means fewer errors, improved waste management and better results in the form of efficiency and accuracy.

CPS-based smart warehouses contain four main components:

- **CPS devices**
  - thousands of CPS devices working together (connected via FID or NFC tags, Wi-Fi, Bluetooth technologies, cameras),
  - need to schedule the communication among the CPS devices efficiently.
- **Inventories**
  - know their status and location context according to the data reported by the attached devices.
- **Robots**
  - collaboratively accomplish some tasks that are repetitive and harmful to human beings (navigating in the environment for specific purposes).
- **Human beings**
  - recognize their gestures or other activities to do warehouse operations (only responsible for sending instructions to the warehouse and monitoring operations).

According to [14] humans can interact intuitively with the vehicles, and they are capable of understanding voice and gesture commands. Industry 4.0 promises new approaches for providing machines with the innate human ability to orient themselves without expensive aids. Focusing on smart vehicles, in the context of Warehouse 4.0 it is essential to eliminate inefficiencies of traditional forklifts. More advanced approaches lead to changes in this generation of driverless vehicles. The limitation of predefined routes of such vehicles can be changed to flexible reactions depending on momentary needs.

3. Factors influencing warehouse efficiency

One of the most significant factors influencing warehouse efficiency is the process accompanying the material flow. Storage in a warehouse is usually carried out over short distances, usually in the order of metres and is carried out using handling devices. The method of handling is thus dependent on the concept of the handling unit and the type of handling device used. [4]

In addition to the process that accompanies the flow of material, other factors affect warehouse efficiency. In total, six primary factors can be defined and sub-factors are briefly described for each significant factor.

1) Spatial layout of the warehouse

- material flow – logical continuity of operations and activities,

- stock availability – how much stock is available, first-in, first-out (FIFO), batch number, expiration date,
- space utilization – maximize warehouse space (analysis of 3D space, principles and integrated spatial standards),
- stock flow rate,
- size of space needed for non-technological processes (manipulation), [15]
- the height of the warehouse and other restrictive building elements of the warehouse,
- a smaller warehouse has advantageous aspects:
  - shorter transport distances,
  - people are closer and it is easier to cooperate, [16]
- these attributes influence the size of the warehouse and they influence each other, as is shown in Figure 1,

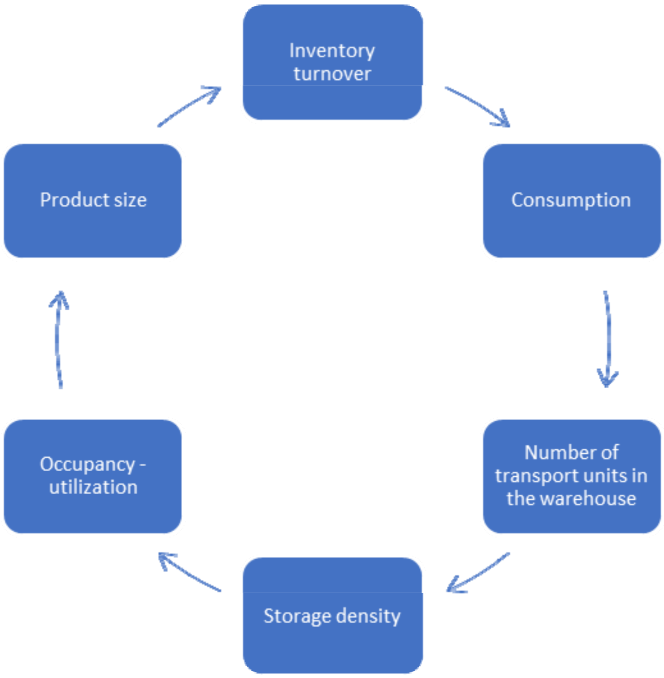

Fig. 1 Mutual dependency of individual factors [16]

- it is advisable to use outer walls for placing the shelves,
- placing material in currently available locations helps utilization (not fixed material location), [16]
- the warehouse layout is based on the same settings as in the case of the production layout design (U structure, L structure, circle, spine structure, etc.). [17]

2) Type and quantity of storage units

- material size and space needed - material space (occupancy), [18]
- utilization of location – productivity is between 70% and 90% and consumption varies accordingly, [19]
- need for sufficient space for circulation,
- need for sufficient storage space,
- type of packaging units,
- labelling and identification, suitability for automation. [20, 21]

3) Technology used for storage

- size of storage and loading area, their ratio determines how technology can be used,
- what technology is currently on the market (modernization),
- how technology meets production requirements (related to supply methods),
- how technology affects warehouse processes (such as automated systems). [16]

4) Process management

- how the process is set – inputs, outputs, resources, certification,
- information provision and support,
- warehouse information systems. [21]

5) Transport equipment

- how the transport equipment matches storage technology,
- the cost of the transport equipment itself,
- transport distance – it affects shipping costs (part of storage costs),
- what is the efficiency of using transport technology. [16]

6) Material placement in the warehouse

- by changing the deployment of material in a warehouse, it is possible to increase warehouse efficiency,
- availability of materials,
- analysis of warehouse locations. [22, 23]

Also, errors and deficiencies are mentioned that may occur during the storage process itself. The types of shortcomings and potential waste are as follows:

- excessive manipulation,
- low utilization of storage space, [24, 25]
- low utilized loading area (we store air),
- low utilization of loading area and handling units,
- excessive maintenance costs and outages caused by obsolete equipment, [26]
- obsolete methods for receiving and dispatching goods, [27]
- unused or misused information systems,
- unused transmission capacity and human capital. [28, 29]

Research shows that 95% of the time related to the material flow in the production up to the finished product is spent on just handling and delaying or the time is wasted. [30]

By defining the location of the material inside the warehouse the transport distance is to be determined and this directly affects storage costs. Therefore, attention can be devoted to individual items that may create problems resulting in the warehouse being managed effectively. It is relatively simple and effective to use the ABC analysis. This is based on the Pareto principle, where 20% of stored materials represent 80% of the company's financial transactions. [31] Another publication [32] presents and validates the use of the ABC classification for inventories and their location. The ABC curve method is used to determine placements that have higher financial flux. The authors [33] state that the location of the material in the warehouse is dependent on the material movement index. Materials with a higher index should be placed at terminals.

Another method used is a multi-criteria analysis is called the Analytic Hierarchy Process (AHP). AHP determines which criteria (consumption/call-offs, weight, financial transactions and seasonality) should be prioritized. It is different from the ABC method because it can link the analysis of several criteria to determine the importance of materials. For example, in [34] the use of multi-criteria AHP is proposed to prioritize inventory by applying it to reverse logistics. The methods such as ABC and AHP are primary classification tools for prioritizing materials. Based on this information, it is clear that methods already exist for improving the location of the material in a warehouse.

3.1 Storage rationalization

In general, rationalization can be considered as a set of activities that are used to improve industrial production systems and their ongoing production processes through optimal connection and efficient use of all their elements. It is a never-ending, time indefinite process of improvement, particularly for improving the production system. The target of rationalization is to achieve maximum productivity while minimizing costs. [35]

Rationalization of storage is based on changing the conditions in a specific warehouse taking into account the requirements of specific customers and suppliers. During the rationalization, it is necessary to choose and implement a suitable method of storage and a suitable method of stock distribution for the whole warehouse and individual parts. [36]

3.2 Suitable method of storage

The choice of a storage method generally depends on the business strategy and characteristics of the inventory. Authors [3, 37] have a similar view on storage methods. They differentiate between the two following storage methods:

- floor storage (block and row storage),
- rack storage (special racks, flat goods racks, truss racks, pallet racks).

Another possible view of storage methods is offered by the authors [38, 39, 40], who differentiate between:

- free storage, stacking and shelf storage.

In this paper, we use a combination of storage methods according to authors [38, 39] with the differentiation established by authors [3, 37].

3.3 Suitable method of stock distribution

After receiving goods in the warehouse, it is necessary to determine where a particular item should be placed. This decision has a fundamental impact on labour productivity as it affects the method of material picking or replenishment, length of transport routes, etc. [41]

Because changing the conditions affects the company, the rationalization can be done by choosing a method which is connected to the current warehouse conditions and current technical development. The primary methods of stock distribution in a warehouse are [3, 42, 43]:

- fixed storage (storage in dedicated locations), interchangeable storage (random, chaotic, free) and zone storage

3.4 Rationalization of storing and picking

Rationalization of storing and picking is based on picking optimization, which has several possible systems and procedures. Picking order has been classified in [44]. The individual picking classes are assigned to methods that facilitate picking (order of picking). Methods can be divided into two primary groups, in the first group, a warehouse worker goes to the goods, and in the second one, the goods go to the warehouse worker.

Warehouse worker goes to the goods - The general description is that the worker goes through the stock and collects individual parts of the order. This method can be extended to the visualization and signalling of the location of goods in the warehouse, for example, by Pick-by-light, Pick-by-voice, portable terminal guidance, use of semi-transparent glasses for navigation, reverse picking or two-stage picking. [45]

Goods go to the warehouse worker – The worker stands at his/her workstation, and the individual items of the order come to him/her. The following systems can be used here: gravity racks, rotomat, automatic goods delivery, sorting systems, box collection systems, fully automatic systems, or robots and automatic pickers without human involvement in the picking process. [45, 47] It is important to note that it is essential to take into account the safety requirements when modern technologies are used. [46] These systems are mentioned at the beginning of the paper.

3.5 Costs and investment in rationalization

The proposal of rationalization should end with a statement of the suitability of the individual rationalization solution. Therefore, it is necessary to clearly define the metrics to be used in this evaluation. It is logical to use multi-criteria decision making that shows what a suitable option for rationalization is. However, a large number of rationalization proposals imply the need for investment. [48, 49]

For this reason, one of the evaluation criteria must also be the investment level. The investment and storage costs are described below.

3.5.1 Investment costs

It is necessary to define the criteria for choosing an appropriate method for assessing the investment and its costs. These criteria, based on literature research, are:

- the method must be robust enough – it must be sufficiently general and reasonably detailed,
- the method must take time into account – the expected sustainability of the solution is more than one year,
- it must evaluate the savings/profit from the investment,
- it must be a commonly used method for assessing investment.

Based on the requirements and the literature research, it is reasonable to use one of the dynamic investment evaluation methods, namely, the Net Present Value (NPV) method. The advantage of this method is that it can describe any cash flow as well as the fact that the result is the absolute value of the investment benefit at today's prices [50].

3.5.2 Operating costs

One of the essential cost areas of each company is the cost of logistics or costs associated with the logistics activities of the company. These costs are essential because they have a direct impact on operating margins, and by reducing them significant savings can be achieved.

Logistics costs can be divided into five primary areas that are interconnected. All key logistics activities are not necessarily within the competence of the logistics department, yet they all have a significant impact on the company's logistics activities. [36] Logistics costs are therefore divided into customer service level, transport costs, acquisition and maintenance costs, storage costs and information system costs. A detailed description of these groups is beyond the scope of the paper.

4. List of abbreviations and definitions:

RFID – Radio-frequency identification uses electromagnetic fields to automatically identify and track tags attached to objects.

AGV – An automated guided vehicle or automatic guided vehicle is a portable robot that moves along marked long lines or wires on the floor, or uses radio waves, vision cameras, magnets, or lasers for navigation.

ROI – Return on investment is a ratio between net profit (over a period) and cost of investment (resulting from an investment of some resources at a point in time).

CPS – A cyber physical system is a system in which a mechanism is controlled or monitored by computer-based algorithms.

NFC – Near-field communication is a set of communication protocols for communication between two electronic devices over a distance of 4 cm (1 1⁄2 in) or less.

W-Fi – Wi-Fi is a family of wireless networking technologies, based on the IEEE 802.11 family of standards, which are commonly used for local area networking of devices and Internet access.

FIFO – first-in, first-out means that the oldest inventory items are recorded as sold first but do not necessarily mean that the exact oldest physical object has been tracked and sold.

ABC – ABC analysis is an inventory categorization technique.

AHP – Analytic hierarchy process is a structured technique for organizing and analysing complex decisions based on mathematics and psychology.

NPV – Net present value or net present worth (NPW) applies to a series of cash flows occurring at different times.

5. List of assumptions based on literature review:

- Warehousing helps the company to improve the quality of the services provided, thereby achieving a better level of customer satisfaction while at the same time reducing costs through storage.
- Three basic storage functions are transfer of products, storage of products and transmission of information.
- By optimizing storage costs and ordering costs you can determine the optimal order size and delivery cycle from the supplier.
- It is crucial to implement all logistics processes within the organization.
- Logistics is an uneven and irregular process, unlike production, which is paced (takt time)
- Balancing of logistics processes is done during the process of supplying technological units.
- Using intelligent management that is adopted and implemented correctly based on the Industry 4.0 principles and in combination with hardware and software technologies leads to changes in warehousing.
- It is possible to precisely determine the consumption of material and semi-finished products in production concerning the production cycle and takt time.
- Automation is one of the core components of Warehouse 4.0.
- The process accompanying the material flow influences warehouse efficiency significantly.
- In previous years, the emphasis was much more on production processes and there was no conceptual rationalization in logistics.
- Rationalization improves industrial production systems and their production processes through optimal connection and efficient use of all their elements.
- Primary factors influencing warehouse efficiency are spatial layout, type and quantity of storage units, storage technology, process management, transport equipment and material placement.
- Based on the conditions set out with suppliers (and their repeated evaluation), it is possible to determine the necessary level of stock.

6. Evaluation of the theoretical part

The literature research has shown that the primary factors influencing the efficiency of the warehouse are:

- layout of the warehouse,
- type and quantity of storage units,
- technology used for storage,
- process management,
- transport equipment,
- material placement in the warehouse.

As part of the rationalization of the warehouse, it is necessary to focus on all these factors and to create the best possible overall system, which will be interconnected and will strengthen the individual parts that will work synergistically and bring overall improvements.

Some of the factors, such as storage location of the material using the ABC or AHP methods, are currently being explored [51]. Similarly, we already know the optimization methods for deployment of storage technology [52].

However, most sources are based on the use of one storage technology that is not integrated into the rationalization system. Similarly, resources are not commonly associated with efficiency in the use of storage units.

Nowadays, there are many possibilities of automation and implementation of information systems and Industry 4.0 as described in the first section. This leads to the fact that warehouses have plenty of opportunities for savings. To achieve these savings, it will be necessary to implement optimization algorithms directly in the storage systems. So the overall topic of warehouse rationalization is becoming increasingly important now and in the future.

Furthermore, it is essential to note that due to a lack of knowledge, tools and/or time, many warehouse rationalizations are initiated without understanding or finding the root cause of the warehouse malfunction and without searching for real opportunities for improvement. This is why we plan to design a methodology to quickly identify the causes of the problematic flow of materials and information, to identify the main opportunities for improvement and thus provide an objective basis for further decision making.

6.1 Summary of the theoretical framework

The theoretical framework for the methodology was determined based on the literature review. The summary of the theoretical framework is as follows:

- logistics is an uneven and irregular process, unlike production which is paced (takt time),
- balancing of logistics processes is done during the process of supplying technological units,
- it is possible to precisely determine the consumption of material and semi-finished products in production concerning the production cycle and the takt time,
- previously, the emphasis was much more on production processes and there was no conceptual rationalization in logistics,
- by optimizing storage costs and ordering costs one can determine the optimal order size and delivery cycle from the supplier,
- according to the conditions set out with suppliers (and their repeated evaluation), it is possible to determine the necessary levels of stock.

7. Proposal of a methodology for rationalization of storage systems in industrial enterprises

The basic premise of this study is that in many cases warehouses are ‘full of air’ due to inappropriate storage technologies and storage units that are not used to their maximum capacity. The input factors for these deficiencies may be:

- stock-keeping units are not optimally filled with material (box is filled with a maximum of 50%; an unnecessarily large box),
- stock-keeping units are in inappropriate locations,
- materials are incorrectly labelled,
- stock-keeping units may contain several types of material.

These deficiencies cause specific types of waste in the storage system, which have been briefly mentioned. Deficiencies may also be in other areas such as the warehouse layout, handling technology, warehouse technology, warehouse management systems, internal logistics, human resources, etc. Therefore, an exact procedure is proposed which should lead to the elimination of ‘air’ and other shortcomings in the storage system. The methodology should focus not only on the optimization of stock levels but also on the efficient use of space and processes to store the necessary stocks. It focuses on the logistics flow in the warehouse with a view on the optimization of the storage location of the material in the warehouse. Secondly, it is aimed at determining the minimum amount of inventory needed to maintain the functionality of supplying material to production.

Compliance and integration of the elements of Industry 4.0 into both the field of internal logistics and the sub-area of the warehouse is also essential. The elements of the Industry 4.0 concept mentioned in the previous sections will be part of the internal logistics issue. This is called Logistics 4.0 and will support the development of this concept. Within this methodology there is a focus on the warehouse, which is referred to as Warehouse 4.0 in the concept of Industry 4.0. The implementation of the elements of this concept should increase the level of complexity of the warehouse and the readiness of the company for implementing Industry 4.0. The term Warehouse 4.0 is used in the description of the methodology.

The overall evaluation system should be based on a mathematical model that comprehensively describes warehouse logistics and optimizes it accordingly. [53] However, it is always necessary to create and evaluate alternatives (variants), which must be evaluated on the basis of the same metrics and according to the capabilities of the warehouse system in the company. The use of appropriate cost parameters as a critical indicator of the suitability of a solution seems to be a suitable benchmark for addressing this topic.

The essence of solving this methodology is based on two steps. The overall cycle should lead to a gradual iterative optimization of the storage location of the material and its quantity in the warehouse in relation to production requirements. During one of the cycles, the second part of the cycle will always be considered a constant. The methodology does not plan to optimize the out-of-stock situation. The relationship with suppliers will not be resolved.

The main attributes of this methodology, which should be verifiable, are also identified as follows:

- The level of inventory is based on production needs and its behaviour is not equal to the level of inventory calculated based on supplier-customer relationships.
- Efficiently used storage units mean savings in the required storage area.
- Choosing the right storage technology saves not only space but also streamlines logistics processes.
- By implementing the appropriate elements of Industry 4.0 in internal logistics - the warehousing area - the level and the readiness of the company for Industry 4.0 will increase.

7.1 Limiting conditions of the methodology for the rationalization of the storage system

The limiting conditions of the proposed methodology for achieving the objectives are:

1. We consider one warehouse – there are no transfers between other warehouses.
2. One entrance to the warehouse system.
3. "One" to "several" outputs from the storage system.
4. "One" to "several" types of storage units and thus "one" to "several" storage options.
5. "One" to "several" material handling systems (manual handling, pallet truck, forklift, etc.).
6. Types of warehouses: warehouses for input material for manufacturing companies in the areas of automotive industry and mechanical engineering.

7.2 Partial objectives of the methodology

Partial objectives are set for the methodology to rationalize the storage system and they correspond to the procedure of the methodology development. These objectives are to

- determine the necessary stock levels in the production and the warehouse concerning the optimum delivery cycle,
- determine the appropriate package size and relevant supply options (e.g. standardization of packages, the same handling units),
- establish methods of warehouse organization in relation to the inputs into the warehouse and use of appropriate material handling equipment,
- determine appropriate technological aspects corresponding to Industry 4.0 in the warehouse (storage technology, material handling equipment, information systems, etc.) and other internal logistics elements suitable for implementation,
- suggest an algorithm of warehouse conduct while changing input or output (package size, different stock levels when production volume changes, etc.),
- suggest a model for economic evaluation [54].

7.3 Methodology areas

The methodology leading to the rationalization of the warehouse is divided into the following five primary areas and sub-areas:

- **Storage unit optimization**
    - optimal stock size
    - type of storage unit
- **Rationalization of storage technology**
    - technical equipment in the warehouse
    - information availability
- **Rationalization of the layout of the warehouse**
    - principles and standards of the storage system layout
    - material flows
- **Rationalization of the put-away and replenishment process**
    - information availability
    - warehouse technology – automation
- **Rationalization of material distribution in the warehouse**
    - suitability of storage
    - optimal storage locations (according to physical parameters, consumption, material flow)

7.4 Model for the current state evaluation and assessment of readiness for the Industry 4.0 concept

The proposed methodology includes also a model of readiness for storage, which assesses all processes in this area and tries to structure them. Using the model, processes are evaluated, the current level is assessed, and the implementation of modern logistics elements aims at increasing the level of logistics processes. The concept of 'storage' is relatively broad, and therefore the model is divided into three subdivisions:

- storage technology,
- information security during storage,
- receiving of material and dispatch.

Another critical parameter are levels of readiness. These levels determine the actual readiness of the business to implement the Industry 4.0. concept. The model has a six-level system (level 0 to level 5), where the highest level (5) includes the technologies and principles of Industry 4.0. Level 4 approaches this characterization, however, in some activities it still retains the concept of human interaction with the device. Each level is characterized and logistical elements for each particular level are assigned. For the purpose of evaluation, a questionnaire is created with questions that are answered by the manufacturing sector, but also, for example, by the head of the department or an IT worker for areas where data are required. Table 1 shows three levels with characteristics and elements.

Table 1 Demonstration of a model of readiness for the implementation of storage technology

Subdivision - Storage technology		
Level	**Characteristics of subdivision**	**Logistics elements**
3	Storage technology connected to enterprise resource planning (ERP). Introduction of automated means and equipment (packaging, palletizing). During the actual storage the material identifiers of the material and the storage location are read.	Terminals connected to ERP online, semi-automated material handling equipment, automated packaging, vertical storage systems (carousels).
4	Storage technologies are integrated into the information environment. Robotic devices receive real-time instructions on which material to store. When robotic devices cannot be used, people receive these instructions via a graphics or voice terminal.	AGVs, automated storage systems, interactive audio or graphics terminal. Vertical lift systems, Smart elevators, Smart Mini-Loaders. Collaborative Robots (load-and-unload).
5	Storage technologies are automatically controlled by ERP. The entire warehouse system is controlled by artificial intelligence or advanced algorithms online and is fully digitized. Autonomous storage technology comprehensive, fully autonomous.	Fully automated warehouse, automated picking equipment, an automated robotic operation for picking, the ability to respond and adapt to the requirements of the external environment. Automated material handling equipment (carts, trains, drones). Smart Fast Rotation Storage Systems.

7.5 Methodology and steps

The methodology is divided into five main steps with sub-steps, as shown in Figure 1.

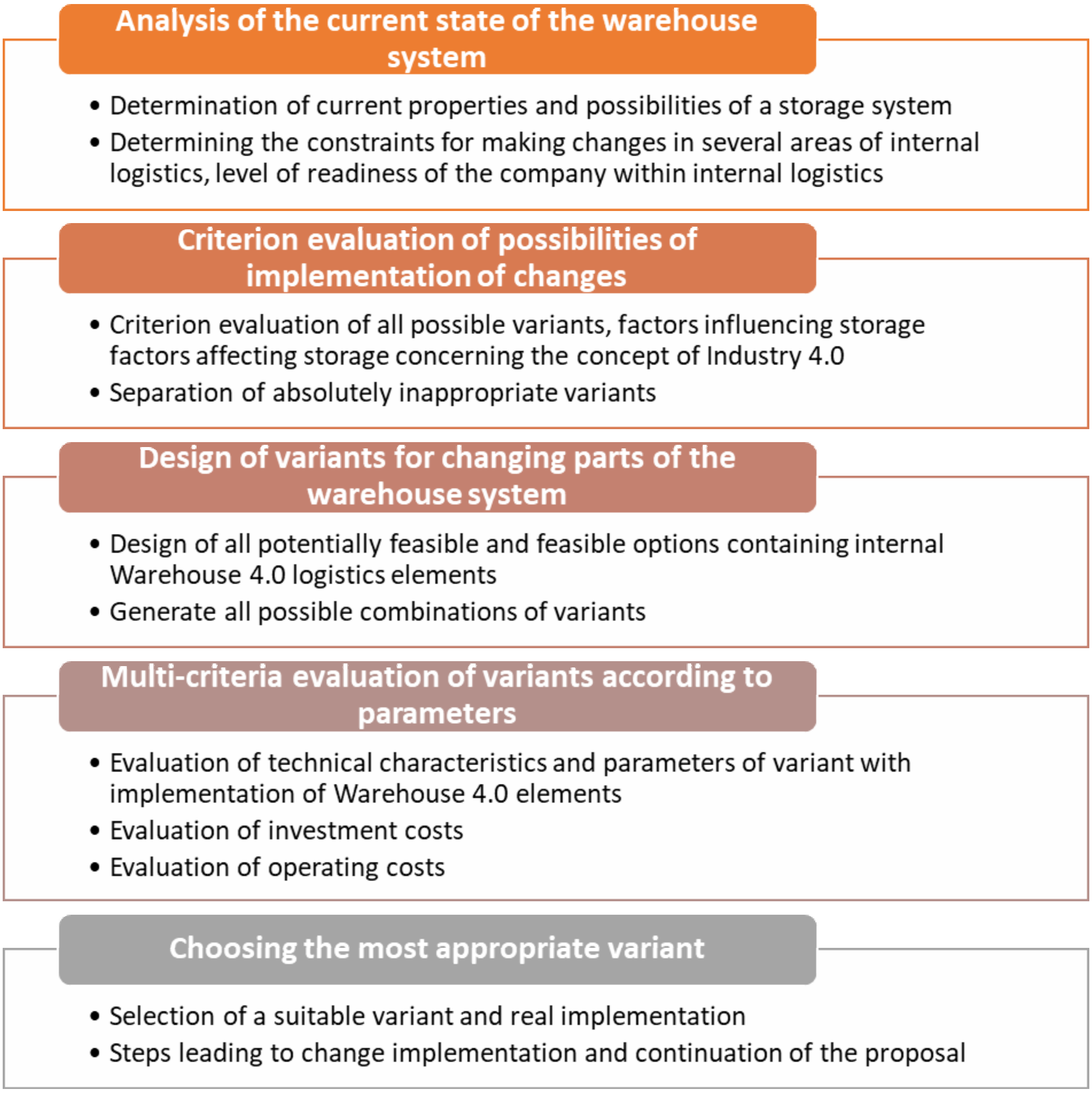

Fig. 2 Design of a methodology to address the rationalization of a warehouse system

Analysis of the current state of the warehouse system

The first step of the methodology serves to describe the current situation as input conditions. A logistics audit focused on internal logistics, specifically on the area of storage, is part of this step. The warehouse system is present in all areas. The current conditions in the following areas are:

– process management of the warehouse system,
– spatial analysis of the warehouse,
– supply,
– time study of internal logistics elements (active and passive).

A comprehensive audit of the warehouse system is therefore required, not only with the results of the hard methodology but also subjective evaluation. The level the enterprise has reached in the area of internal logistics - warehousing within the Industry 4.0 concept - should also be determined, as the proposed methodology is aimed at implementing appropriate elements to create Warehouse 4.0. [55]

Evaluation of possibilities for implementation of changes

The second step serves to separate feasible solutions from infeasible solutions. Essentially, it is a projection of the constraints of step 1 and a comparison of the proposed solution with all possible combinations. An example may be the input factors mentioned in the theoretical part:

- possibility/impossibility or investment level,
- warehouse space restriction or warehouse height,
- material handling equipment and potential equipment of warehouse technology, the possibility of automation,
- systematic delivery into production, etc.

In addition to these essential factors, there are also factors resulting from the Industry 4.0 concept.

Design of variants of changes to the warehouse system

The third step defines possibilities for changes. In this step, we need to define possible solutions for:

- put-away,
- storage,
- picking.

The next step is taken based on these variants.

Multi-criteria evaluation of variants according to parameters

The fourth step carries out a multi-criteria evaluation, which will probably be based on a multi-criteria evaluation of the variants according to Saaty's method. This evaluation includes the described costs from the theoretical part. The main cost criteria are investment and warehouse system-oriented operating costs. Other suitable warehouse utilization indicators include:

- warehouse turnover - t/m^2, or t/m^3,
- load of storage area - t/m^2,
- filling of storage space - m^3,
- shelf storage capacity - m^2,
- productivity per worker per year - t/1 worker,
- operating costs per unit of turnover,
- value of handling equipment per worker and possibly other indicators.

The technical characteristics and parameters of the variant are also evaluated to assess the increase in the technical level of warehouse elements from Warehouse 4.0.

Selection of the most appropriate variant

The fifth step serves as a superstructure above the fourth step, which describes what needs to be changed. It specifies further steps leading to the implementation of the changes. The cost calculation also incorporates investment costs in the implementation of the options, which is one of the criteria for evaluating the options within the methodology.

8. Case study

The case study demonstrates the proposed methodology, focusing on the rationalization of storage spaces. The aim of the case study is to analyse the storage of input material and spare parts in the storage premises as well as the stock needs (determination of the required area for storage). Based on the results of these analyses an appropriate storage method and an appropriate technology for storage to be used are determined. The related effort is to maximize the use of the usable area of the warehouse and to introduce modern logistics technologies that increase efficiency and readiness for Industry 4.0 in the warehouse, but also to maximize possible cooperation with other areas of internal logistics.

8.1 Analysis of the current state of the warehouse system

The whole project begins with calculations of areas that are needed because of the common sense procedure of warehouse rationalisation. The calculation of the warehouse areas is divided into four main parts of the warehouse as follows:

- calculation of warehouse workplaces,
- calculation of the area of the output warehouse (shipping area),
- calculation of the area for picking and feeding carriage,
- calculation of the area and volume of the material in the input warehouse.

It should be mentioned that spatial and data analyses were performed. Within the spatial analysis, 2D layouts as well as 3D layouts for better visualisation and imaginability were created based on plans and drawings of the warehouse workplaces and the warehouse itself. The static calculation of the area needed for warehousing the material was used because of the specific technology, which will be chosen. This stage of the project served to check all the workplaces in the warehouse as well as to make assessment of the area needed for each workplace.

a) Calculation of warehouse workplaces

The area calculation is essential for executing the mapping of actual workplaces. The central workplaces mapped are Incoming inspection A, Incoming inspection B, Shipment, Receipt, Packaging area, Warehouse management office and Foreman office. The current process begins in an outdoor tent used for storage of materials before inspection, from which the materials travel to receipt, then some parts go to the inspection, warehouse positions or cross-dock storage. After the inspection some materials are packed in the packaging area and other materials are delivered to the warehouse location. Carriage/carts are used for manipulation between workplaces. The warehouse area is divided into four parts: Warehouse A–I, Warehouse L–Y, Warehouse Y and Warehouse of consumable materials. Warehouse A–I uses a traditional rack for hand-picking from the floor to the height of almost 3.5 m. Warehouse L–Y is almost the same as warehouse A-I, but the last line of racks is made for a stock of more significant materials (off-shelf materials). Materials in the Warehouses A- I and L–Y are used for storage of small load carriers, i.e. Kleinladungsträger (KLT) in four different sizes and free located materials. Warehouse Y is only used for off-shelf materials and bigger boxes. Warehouse of consumable materials was not evaluated.

b) Calculation of the area of the output warehouse (shipping area)

Based on several parameters and limiting criteria, the area required for the storage of finished products was also calculated. This calculation was based on the data on the expected volume of production in the future for two basic types of product pieces (small and large). The number of stored finished products for two days was calculated on the assumption of production of 20 days per month. Thus, the required amount of stock pieces is calculated as the number of finished products of the group divided by 10 (20 days per month/two-day supply). It has been calculated that an area of 95 m^2 will be required for the storage of finished products with these parameters.

c) Calculation of the area for picking and feeding carriage

Other parts of the warehouse are parking places for trucks receiving material and a parking place for trucks ready to carry items into production. The number of trolleys for receiving the material determined on the basis of calculations and consultations with the customer's representatives is eight, which resembles an area of 11 m^2. The calculation of the space required for trucks carrying items into production was performed on the basis of historical data on the number of picked items over a period of 70 days when the volume of material always increased by 20%, i.e. in the same percentage as the planned increase in production capacity. Three basic types of storage trolleys were set for the calculation before the integration into production: a box – material requirements were less than 20 pieces, single carriage – production requirements were between 20 pieces and 100 pcs, and double carriage – the requirements were over 100 pcs. The analysis subsequently showed that the maximum area needed is equal to 52 m^2.

d) Calculation of the area and volume of the material in the input warehouse

To calculate the required amount of storage space and volume, all racks in the current storage area were surveyed and these positions were recorded in a table for further analysis. Table 2 contains information about a group of shelves, as the shelf is currently referred to. Furthermore, the number of floors of a given shelf is always recorded. Each shelf is further analysed in terms of width, depth and height. From these data, the values of the shelf area were further calculated, and further analysis was performed on these data to design the necessary amount of storage technology. For a more accurate analysis of warehouse positions and the area required for storage of input material, four basic transport units, the so-called stock keeping units (SKUs), which were used for storage in the company, were dismantled and their basic dimensions were recorded.

Table 2 Rack positions in the current state

ID	group of racks	min	max	number of floors	width (mm)	depth (mm)	height (mm)	shelf area (m^2)	rack area (m^2)	average shelf height (mm)
1	**B**	1	14	14	1,260	400	3,300	0.504	7.06	235.7
2	**B**	20	35	16	980	400	3,300	0.392	6.27	206.3
3	**B**	40	54	15	980	400	3,300	0.392	5.88	220.0
4	**B**	60	75	16	980	400	3,300	0.392	6.27	206.3

Within the warehouse, some of the materials were also stored in a free location, so it was necessary to take these positions into account. The material in the storage positions was also analysed in the form of area and volume filling each shelf in the rack for loose material and for each SKU. It is, therefore, possible to say that each SKU underwent analysis by the research team. During the analysis of stored items in the company, a pre-selection of a possible method of storage in the future condition was also performed. Namely, it was estimated for each item which storage technology would be appropriate to be applied for placing the material. The main parameters of the stored material are given in Table 3.

Table 3 Record of stored material

Shelf letter	Shelf no	Free/ KLT	KLT type	Volume	Area	Type of storage technology	No. of KLT	KLT type	Position	Area m^2
E	10	free			75%	lift			E10	0.504
E	12	free			50%	lift			E12	0.504
E	20	KLT	1	25%	100%				E20	0.392
E	21	free			75%	lift	2	low	E21	0.392
E	22	KLT	1	10%	25%				E22	0.392

The results mainly refer to the utilisation of storage space (utilisation of SKU area and shelf area), which is 72% (72.14%), and the volume utilisation of racks and SKUs is 31% (30.88%). However, the free space was identified on the top of racks above the height of 2.5 m. This shows that occupation is relatively good - it is not possible to use an area 100% due to the overfilling of the warehouse. In general, the optimal use of storage technology is 80%-90%. However, the use of shelves and SKUs is poor, it means that 69% of the air is stored in the warehouse - this is where the potential for improvement lies. In the warehouse there are about 30,000 different part numbers and these part numbers are stored in different SKUs. These SKUs are most likely to be unfilled, e.g. the most commonly used SKU stores five different part numbers, each of these parts is low in volume, but has to be stored separately – so the SKU is filled well with respect to the area but poorly with respect to volume.

8.2 Criterion evaluation of possibilities of implementation of changes

The choice of storage technology depends on many factors related to the warehouse, such as the height of the warehouse, the spatial arrangement of the warehouse, the use of rack volume and area, the number and type of SKUs, picking system, etc. The factors that were mentioned in the theoretical part come to the fore here. Furthermore, the following limiting factors and criteria were identified in terms of their reference to this project, which were set together with the company and which the proposed technology must also comply with:

- in the future the design has to allow the supply of all workstations every one or two hours,
- the layout has to support the increase in inventory accuracy from the current 96% to min 98%, the future target being 100%,
- reduction in the total floor space used by the warehouse of min 20%, and at the same time support for the future increase of 20% of the goods stored,
- free of risk of accident and support of the ergonomics of the work – no managers
- respecting FIFO and full material traceability,
- reduction in warehouse full-time employees (FTEs) by increasing efficiency – current average is 1.2 min per kitting item,
- proposal of an efficient layout and part flow from dock to receipt and inside the warehouse from receipt to inspection put-away and to kitting activity,
- preparation for future automatic line feeding possibility of automation by means of laser guided vehicles (LGVs) etc.,
- proposal for efficient material distribution between the central warehouse and other parts of the facility.

8.3 Design of variants of the warehouse system changes

To achieve the objectives mentioned in 7.2 the storage technology needs to be changed. The storage technology was pre-selected from the following technologies (the technologies and their pros/cons were described in detail):

- vertical buffer module – implementation of Warehouse 4.0,
- horizontal carousel – partial implementation of Warehouse 4.0,
- vertical carousel – partial implementation of Warehouse 4.0,
- vertical lift system – implementation of Warehouse 4.0,
- double-storey warehouse with a walking floor – no implementation of Warehouse 4.0.

The pre-selection was made based on the criterion that the necessary requirements are met and it was a direct decision of the company. The pre-selection resulted in two basic options, namely the use of a vertical lift system (lean lift would also be applicable in combination with a vertical carousel) with the implementation of the Warehouse 4.0 concept and a double-storey warehouse with a walking floor without a direct implementation of the Warehouse 4.0 concept.

It is important to mention that the productivity must be achieved. In the vertical lift system solution, a total of 16 vertical lifts would be needed to satisfy the criterion of the storage capacity increased by 20 per cent. If there were one picker per vertical lift, we could reduce the picking time (including scanning and waiting for the preparation of the material in the lift) to 57.5 sec from the original 72 sec. It leads to a workforce reduction, i.e. three workers less are needed. There is a possibility to improve the process in the way that the worker is capable of picking from three vertical lifts. He/she can operate one the vertical lift while the next lifts prepare the material inside. This leads to a reduction in the picking time to 24.6 sec. There would be a total workforce reduction of ten workers.

The double-storey warehouse with a walking floor is optimized to increase the level of ergonomics and the storage capacity by 20 per cent. This, unfortunately, leads to an increase in the picking time to 86.5 sec from the original 72 sec. One additional worker is needed afterwards.

8.4 Multi-criteria evaluation of variants according to parameters

Two pre-selected options were analysed in detail (the first one with Warehouse 4.0 elements implemented, the second one without these elements implemented) and relevant criteria were calculated. The overview of the main criteria is shown below.

Table 4 Overview of main criteria

	Warehouse area	**Storage capacity**	**Picking time**	**MUDA (results)**	**Investment cost**	**Operating cost reduction (per year)**
Current state	**796 m^2**	1,679 **m^2**	72 s	-	-	-
Vertical lift s.	**796 m^2**	2,415 **m^2**	up to 25 s	+	582,000 EUR	160,000 EUR
Double-storey	**796 m^2**	2,419 **m^2**	86,5 s	+/-	371,000 EUR	-16,000 EUR

Muda analysis concentrated on waste also involves Mura irregularity and Muri overburden analysis. Symbol + under MUDA (Table 4) stands for the general recommendation and the symbol – means that the variant is not recommended.

The operating cost reduction in the double-storey warehouse is not represented by positive values, mainly due to the higher picking time in the variant (one additional worker is needed in comparison to the original status).

The calculation of the net present value of the variants leads to a negative value in the variant of the double-storey warehouse in comparison to the variant of the vertical lift system mainly due to the productivity reason described in the third part of the case study. This means that the vertical lift system is a better solution according to these criteria.

The application of Saaty's method with the calculation of the included priorities was made in this step of the case study.

8.5 Selection of the most appropriate variant

Saaty's method resulted in the recommendation for introducing the vertical lift system. The choice of this variant also increases the technical level of the warehouse elements related to Warehouse 4.0. The solution can be summarized by means of the list of pros and cons:

- Pros
    - possibility to store even large materials,
    - possibility to store more materials on one shelf - suitable for materials collectively picked,
    - high load capacity,
    - technology verification,
    - good ergonomic properties - the dispensing window is at the optimum height,
    - increase in inventory accuracy,
    - removal of long transitions and passages of the warehouse. One picker will handle two to three lean lifts from which it will pick. Practice confirms that the most efficient way is the assignment of three lean lifts to one picker.
- Cons
    - single point of failure - this disadvantage can be eliminated by placing one item in several lean lifts, and this avoids the problem of not being able to pick on a single device while improving picking time,
    - an intelligent system for managing and sorting requirements from production - especially for pre-preparation of shelves in lean lifts for picking – has to be purchased too.

From all of the scenarios, this is the best solution to the problems because it supports or eliminates the problems and takes the constrains into consideration. The investment will be needed in this scenario, but operational costs will drop.

9. Conclusion

The aim of this paper is to propose a methodology related to storage system rationalization in warehouses of industrial companies. The aspects of storage unit optimization, storage technology rationalization, warehouse facility layout rationalization, rationalization of storing and picking and rationalization of the storage structure are included. They are evaluated by multi-criteria evaluation with the emphasis on costs.

The methodology is widely applicable in different kinds of warehouses from the "simplest" warehouses with manual manipulation with little or no connection of data to the warehouse information system or external source of data to almost fully automatized complex warehouse systems.

The methodology considers technology, processes and human operators. It emphasizes the new concept of Warehouse 4.0, including general Industry 4.0 warehouse applications. The proposal of the methodology concentrates on two purposes. Firstly, to eliminate problems causing waste in the internal logistics, i.e. storage. Another goal of the methodology is to increase the level of the company in the internal logistics/warehousing with relation to the increase in business readiness for the Industry 4.0 concept by implementing appropriate elements corresponding to this concept. By implementing vertical lift systems, we increased the warehouse capacity without enlarging the warehouse area. This methodology also has the potential to rationalize a wide variety of warehouses. Further research can focus on connecting warehouses to intra-manipulation. In this way, the number of pickers (human workers) could be reduced. Future application has potential in automatized packaging. This can even extend to fully automated guided vehicles and lights-out manufacturing.

For industrial companies, the path to Industry 4.0 does not have to mean an immediate significant investment in the complete replacement of equipment or modernization of the entire company. It is possible to move towards a smart company gradually without the need for massive direct investments. It is essential to start digitization and set basic principles, firstly on a small scale, and then expand the functionality and add other objects and services to this network.

The purpose of the paper is to share our approach to summarizing the factors influencing effectiveness of the warehouse and the methodology proposal itself. This information can be an inspiration for other research institutions to consider the aspects of this subject matter that can otherwise be overlooked.

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REFERENCES

[1] Martin, H. 2014. *Transport- und Lagerlogistik.* Wiesbaden: Springer Fachmedien Wiesbaden. https://doi.org/10.1007/978-3-658-03143-5.

[2] Gros I. *Logistika*. Praha: Vydavatelství VŠCHT; 1996.

[3] Sixta, J., & Mačát, V. (2005). Logistika: teorie a praxe. CP Books, as.

[4] Daněk, J., & Plevný, M. (2005). Výrobní a logistické systémy. Západočeská univerzita.

[5] Mařík, V. (2016). Průmysl 4.0: výzva pro Českou republiku. Management Press.

[6] Wang, K. (2016, November). Logistics 4.0 Solution-New Challenges and Opportunities. In 6th International Workshop of Advanced Manufacturing and Automation. Atlantis Press.

[7] Bonkenburg, T. (2016). Robotics in logistics: A DPDHL perspective on implications and use cases for the logistics industry. DHL Trend Research, 1(1), 1-5.

[8] Berger,R.: Study „Of Robots and Men – in logistics: Towards a confident vision of logistics in 2025". 2016.

[9] Liu X, Cao J, Yang Y, Jiang S. CPS-Based Smart Warehouse for Industry 4.0: A Survey of the Underlying Technologies. *Computers*. **2018**;7(1):13. https://doi.org/10.3390/computers7010013

[10] Juntao L. Research on Internet of Things Technology Application Status in the Warehouse Operation. *International Journal of Science, Technology and Society.* **2016**;4(4):63. https://doi.org/10.11648/j.ijsts.20160404.12

[11] Lerher T. Warehousing 4.0 by using shuttlebased storage and retrieval systems. *FME Transaction.* **2018**; 46(3):381-385. https://doi.org/10.5937/fmet1803381l

[12] ZebraTechnologies. Building the Smarter Warehouse: Warehousing 2020: *Redefining Supply Chain Automation in the Age. North America Report, North America*: Zebra Technologies, 2016.

[13] Vijayaraman B, Osyk B. An empirical study of RFID implementation in the warehousing industry. *The International Journal of Logistics Management.* **2006**;17(1):6-20. https://doi.org/10.1108/09574090610663400

[14] AG B. Smart Warehouse Logistics in the Age of Industry 4.0 – An Intelligent Reach Truck with Basler ToF Cameras Makes It Possible. – New Success Story. Basler AG. https://www.baslerweb.com/en/company/news-press/news/smart-warehouse-logistics-in-the-age-of-industry-40-an-intelligent-reach-truck-with-basler-tof-cameras-makes-it-possible-new-success-story/10254/. Published 2020. Accessed June 11, 2020.

[15] Warehouse Design & Layout - Warehouse Consultants | Logistics Bureau. Logisticsbureau.com. https://www.logisticsbureau.com/warehouse-design-and-layout-consultants/. Published 2020. Accessed June 11, 2020.

[16] Frazelle E. World-Class Warehousing And Material Handling. New York: McGraw-Hill Education; 2016.

[17] Caron F, Marchet G, Perego A. Optimal layout in low-level picker-to-part systems. *Int J Prod Res*. **2000**; 38(1):101-117. https://doi.org/10.1080/002075400189608

[18] Macáková, L. (2010). Mikroekonomie: základní kurz. Melandrium.

[19] Horejší, B., Soukupová, J., Macáková, L., & Soukup, J. (1996). Mikroekonomie.

[20] Salvendy G. *Handbook Of Industrial Engineering*. New York: Wiley; 2001.

[21] Berry J. Elements Of Warehouse Layout. *Int J Prod Res*. **1968**;7(2):105-121. https://doi.org/10.1080/00207546808929801

[22] Rouwenhorst B, Reuter B, Stockrahm V, van Houtum G, Mantel R, Zijm W. Warehouse design and control: Framework and literature review. *Eur J Oper Res.* **2000**;122(3):515-533. https://doi.org/10.1016/s0377-2217(99)00020-x

[23] Svoboda, V., & Latýn, P. (2003). Logistika. Vydavatelství ČVUT.

[24] Drahotský, I., & Řezníček, B. (2003). Logistika: procesy a jejich řízení. Computer press.

[25] Gros, I. (2003). Kvantitativní metody v manažerském rozhodování. Grada Publishing.

[26] Jeřábek, K. Logistika. Praha: České vysoké učení technické, 1998.

[27] Konečný, M. (1999). Logistika v systému řízení podniku. Vysoká škola báňská-Technická univerzita, Strojní fakulta.

[28] Muther, R., & Haganäs, K. (1973). Systematické navrhování manipulace s materiálem (SHA): Určeno také stud. na všech vys. a stř. odb. školách techn. a ekon. směru. SNTL.

[29] Ptáček, S. (1998). Logistika. Vysoká škola báňská-Technická univerzita Ostrava, Fakulta metalurgie a materiálového inženýrství.

[30] Horváth, G. (2000). Logistika výrobních procesů a systémů. Západočeská univerzita, Strojní fakulta.

[31] Slack N. Administração Da Produção. São Paulo (SP): Atlas; 1999.

[32] Tinelli, L. M., Vivaldini, K. C. T., & Becker, M. (2014). Product positioning optimization in intelligent warehouse. In *ABCM Symposium Series in Mechatronics,* v. 6.

[33] Petersen C, Aase G, Heiser D. Improving order-picking performance through the implementation of class-based storage. *International Journal of Physical Distribution & Logistics Management.* **2004**;34(7):534-544. https://doi.org/10.1108/09600030410552230

[34] Magalhães, A. P. D. S. (2011). Logística reversa de eletrodomésticos da linha branca: processo de escolha pelo Método de Análise Hierárquica (AHP) (Doctoral dissertation, Universidade de São Paulo). https://doi.org/10.11606/D.18.2011.tde-17062011-171728

[35] Broum, T., Dvorak, J., & Kleinova, J. (2011, January). Value optimization and risks elimination of product. In *Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium* (Vol. **22**, No. 1, pp. 757-758).

[36] Srajer, V.; Broum, T.; Kleinova, J. Design of the spatial arrangement of a production system using value analysis, Creating Global Competitive economies - A 360-degree Approach, *International Business Information Management Association (IBIMA),* Milan, Italy, 2011

[37] Hádek, L. (2008). Nákup a zásobování. Vysoká škola podnikání.

[38] Vaněček, D. (2008). Logistika. *Jihočeská univerzita*, Ekonomická fakulta.

[39] Schulte, C. (1994). Logistika. Přel. G. Tomek; A. Baudyš. 1. vyd.

[40] Čujan, Z., & Málek, Z. (2008). Výrobní a obchodní logistika. *Univerzita Tomáše Bati ve Zlíně*.

[41] Simon, M.; Broum, T. Layout calculations related to product insourcing, Proceedings of the 29th DAAAM International Symposium, Zadar, Croatia, 2018. https://doi.org/10.2507/29th.daaam.proceedings.045

[42] Gudehus, T. Comprehensive Logistic, *Springer*, London, **2011**

[43] Lambert, D. M., & James, R. (2005). Stock a Lisa M. Ellram. Logistika. 2. vyd. Brno.

[44] Frazelle, E. H., & Sharp, G. P. (1990). How to Design, Operate, Select, and Improve Order Picking Systems. *In Order Picking Workshop, Material Handling Research Center*, Georgia Institute of Technology, Atlanta, Georgia.

[45] Basl, J. (2017). Pilot Study of Readiness of Czech Companies to Implement the Principles of Industry 4.0. *Management And Production Engineering Review*, **8(2)**, 3-8. https://doi.org/ 10.1515/mper-2017-0012

[46] Broum, T., & Simon, M. (2020). Safety requirements related to collaborative robots in the Czech republic, *MM Science Journal*, **2020(1)**, 3852-3856. https://doi.org/10.17973/mmsj.2020_03_2019136

[47] Broum, T., & Šimon, M. (2019, July). Preparation of Collaborative Robot Implementation in the Czech Republic. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

[48] Broum, T., Gorner, T., Kleinova, J., & Simon, M. (2012). Increasing the value of ergonomic design of workplace in compliance with limit costs. In *Proceedings of the International Conference of DAAAM Baltic" Industrial Engineering"*, ISSN X (Vol. 2346612, pp. 413-418).

[49] Broum, T., & Kleinová, J. (2018). The cumulative functions concept. *Annals of DAAAM & Proceedings*, **29**.

[50] Cechura, T.; Broum, T.; Kleinova, J. Economic analyses and assessment of manufacturing processes and products within the life cycle product project in a digital business environment, 7th DisCo Conference Reader: *New Media and Education,* Prague, Czech Republic, **2012**

[51] Tinelli, Livia & Vivaldini, K. & Becker, Marcelo. (2013). Product positioning optimization in intelligent warehouse. *ABCM Symposium Series in Mechatronics*, Sao Carlos, **2014**, Vol. 6

[52] Kostrzewski, M. (2012). Logistics facilities designing method-a study of a procedure for logistics facilities designing and its ol09 software implementation. *Archives of Transport*, **24**, 321-340.

[53] Poór, P., & Basl, J. (2019). Readiness of Companies in Relation to Industry 4.0 Implementation.

[54] Dobránsky, J., Pollák, M., & Doboš, Z. (2019). Assessment of Production Process Capability in the Serial Production of Components for the Automotive Industry. *Management Systems In Production Engineering*, **27(4)**, 255-258. https://doi.org/10.1515/mspe-2019-0040

[55] Pollák, M., & Tkáč, J. (2019). Enterprise Information Data Management System for Small Manufacturing Company. *TEM Journal: Technology, Education, Management, Informatics. Association for Information Communication Technology Education and Science*, **2019**, Vol. 8, no. 4, pp. 1169-1175,

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