KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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DESIGN OF OIL STOREHOUSE

Final Master's Degree Project

Supervisor
Assoc. Prof. Dr. Inga Skiedraitė

KAUNAS, 2015

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FACULTY OF MECHANICAL ENGINEERING AND DESIGN

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Mechatronics (code 621H73001)

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"Design of oil storage"

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SUMMARY

The final Master‘s project examines the excisting smart warehousing options and introduces a possible solution of smart warehousing for company Autepa UAB by introducing a loading-unloading robot to the work environment. The analysis of the warehouse capacity is conducted, new areas are introduced and the layout of the warehouse is adapted to the instalement of the newly designed robot. Having adopted the new areas of the warehouse, the appropriate lift and unloading platform have been selected. To assure the relevance of the lift, buckling analyses have been carried out for the two types of possible lifts. The necessary sensors have been selected and the operational algorithm has been compiled. After the robot design has been finished, security and fire safety systems have been overviewed and chosen according to the warehouse layout.

Key words: smart warehouse, storage layout, robot, fire safety, security.

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SANTRAUKA

Baigiamajame Magistro projekte buvo nagrinėjami jau sukurti išmaniųjų sandėlių sprendimai ir pristatytas galimas išmanaus sandėlio prototipas įmonei UAB Autepa. Šis prototipas paremtas pakrovimo-iškrovimo roboto įvedimu į darbo aplinką. Buvo atlikta sandėlio erdvės analizė, sukurtas naujas sandėlio išdėstymas bei pristatytos naujai sukurtos erdvės, pritaikančios sandėlį roboto įvedimui. Suplanavus sandėlio išdėstymą, parinkti keli keltuvų tipai roboto kūrimui. Abiems keltuvams buvo atliktos gniuždymo analizės ir pasirinktas antrasis keltuvo tipas. Parinkti jutikliai bei sudarytas roboto valdymo algoritmas. Atsižvelgiant į sandėlio išdėstymą, išmaniajam sandėliui parinkti priešgaisrinės saugos ir vagystės prevencijos prietaisai, bei pateiktas jų išdėstymas.

Raktiniai žodžiai: išmanusis sandėlys, sandėlio išplanavimas, robotas, priešgaisrinė sauga, apsauga.

KAUNO TECHNOLOGIJOS UNIVERSITETAS
MECHANIKOS INŽINERIJOS IR DIZAINO FAKULTETAS

Tvirtinu:

Gamybos inžinerijos katedros vedėjas

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(parašas, data)

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(vardas, pavardė)

MAGISTRANTŪROS STUDIJŲ BAIGIAMOJO DARBO UŽDUOTIS
Studijų programa MECHATRONIKA

Magistrantūros studijų, kurias baigus įgyjamas magistro kvalifikacinis laipsnis, baigiamasis darbas yra mokslinio tiriamojo ar taikomojo pobūdžio darbas (projektas), kuriam atlikti ir apginti skiriama 30 kreditų. Šiuo darbu magistrantas turi parodyti, kad yra pagilinęs ir papildęs pagrindinėse studijose įgytas žinias, įgijęs pakankamai gebėjimų formuluoti ir spręsti aktualią problemą, turėdamas ribotą ir (arba) prieštaringą informaciją, savarankiškai atlikti mokslinius ar taikomuosius tyrimus ir tinkamai interpretuoti duomenis. Baigiamuoju darbu bei jo gynimu magistrantas turi parodyti savo kūrybingumą, gebėjimą taikyti fundamentines mokslo žinias, socialinės bei komercinės aplinkos, teisės aktų ir finansinių galimybių išmanymą, informacijos šaltinių paieškos ir kvalifikuotos jų analizės įgūdžius, skaičiuojamųjų metodų ir specializuotos programinės įrangos bei bendrosios paskirties informacinių technologijų naudojimo įgūdžius, taisyklingos kalbos vartosenos įgūdžius, gebėjimą tinkamai formuluoti išvadas.

1. Darbo tema

Design of Oil Storehouse / Alyvos sandėlio kūrimas

Patvirtinta dekano 2015 m. gegužės mėn.11 d. įsakymu Nr. ST17-F-11-2

2. Darbo tikslas

Suprojektuoti išmanųjį alyvos sandėlį turimai erdvei (20 x 50 metrų) pritaikant alyvos iškrovimo robotą bei parenkant ir priešgaisrinės ir vagystės prevencijos prietaisus ir juos išdėstant sandėlyje.

3. Darbo struktūra

Esamų išmaniųjų sandėlių apžvalga; sandėlio išdėstymo analizė bei naujų erdvių kūrimas; roboto prototipo bei jo valdymo kūrimas; sandėlio priešgaisrinės saugos bei apsaugos nuo vagysčių elementų parinkimas ir jų išdėstymas.

4. Reikalavimai ir sąlygos

Sandėlio erdvei (20 x 50 x 4 m) parinkti lentynas, kurias išdėsčius sandėlyje robotas galėtų judėti saugiai ir efektyviai. Užtikrinti darbo saugos, priešgaisrinės saugos ir apsaugos nuo vagysčių reikalavimus.

5. Darbo pateikimo terminas 2015 m. birželio mėn. 1 d.

6. Ši užduotis yra neatskiriama baigiamojo darbo dalis

Išduota studentei Evelinai Kinderevičiūtei

Užduotį gavau _______________________ (studento vardas, pavardė) __________2015 02 02 (parašas, data)

Vadovas _______________________ (pareigos, vardas, pavardė) __________2015 02 02 (parašas, data)

CONTENT

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Nowadays the development of technologies is growing extremely fast and consumerism is increasing in the pace which is really hard to track. In order to ensure the quality and speed of the provided service or commodity, all companies are forced to introduce new smart technologies into their work environment. The growth of mechatronics allows delegating performance of manual work, which sometimes is unpleasant, dangerous or time-consuming, to robots and kinds of mechatronic systems.

The most important role of other new technologies is making life easier and more convenient. As time passes, more and more companies are solving stocking, packaging and warehousing problems by integrating different types of mechatronic and IT systems in daily work.

The most popular solutions are loading and unloading robots, packaging robots, fire and burglary alarms. The American company KIVA Systems is one of the most automated warehousing companies. KIVA Systems is a subsidiary of Amazon.com and processes plenty of orders every day. Every order has to be thoroughly and quickly picked and every purchased item has to reach the designated customer.

To make the process of handling commodities faster, a new approach was introduced by Kiva. The idea of the solution ensures that orders fulfilled promptly and to the point in terms of allocation. The new system is smarter, because commodities move to workers and not the other way around, as is typical. Every worker has his/her own work station where electronic orders arrive from the online system and the information about the required good is sent to the drive units. Kiva describes the operational principle of the system quite simply:

"*The software sends Kiva's robotic drive units following a grid of two-dimensional bar codes that are stickered to the floor to navigate their way to mobile shelves (pods) containing the desired inventory.*

When the robotic drive unit reaches the correct location on the warehouse floor, it positions itself beneath a pod and lifts it from the ground to carry it to a work station. At the station, with the aid of a laser pointer, pick lights, computer screen and barcode scanner, a human worker selects the desired items for the orders he or she is working on.[1]

There is another way of looking into smart warehousing. Lithuanian company Autepa UAB imports Mabanol oil. Main commodities to be stored are (cartons) boxes of oil in 1 and 5 litre bottles and drums of 60 and 208 litres. The boxes are stored on the shelves and the drums usually remain on Euro pallets. The most difficult job is to stack all the boxes onto 2-metre high shelves.

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[1] The website of Smart Warehouse Systems. Internet access - http://smartwarehouse.com/sws-aurora-web-warehouse-management

The aim of this project is to design a smart oil storehouse in the given space (20 x 50 x 4 m). It can be done by introducing a robot to facilitate arrangement of cartons and designing a fire and burglary security systems.

The smart warehouse project for this company is different from Kiva's, because the main goal is the allocation of goods when they arrive to the warehouse rather than fulfilling any order.

The tasks concluded to implement the aim of the project:

1. To design the warehouse space by choosing the racks.
2. To propose the design of the loading-unloading robot.
3. To create control algorithm of the robot and choose appropriate elements.
4. To create a layout of fire and burglary safety and choose the elements.

1. REVIEW OF EXCISTING STORAGE SOLUTIONS

1.1 Description of smart warehouse

Smart warehouse in general is a place to load, unload, and store desired commodities, to be able to fulfil an order as easy as possible and to be able to react to any danger that might occur because of burglary, fire or flood. There are several different ways to look at smart warehousing or storing goods and fulfilling orders.

1.2 Smart warehouse software

Most of the so called smart warehouses use the cheapest equipment which can be found nowadays – it's warehouse management software. One of the companies creating warehouse management software is Smart Warehouse Systems. As stated by the name, they are creating software to facilitate daily labour of a warehouse keeper by introducing the mentioned software to the warehouse environment. SWS Aurora (the software introduced by Smart Warehouse Systems) is a web-based Warehouse Management System. This software, which can be entered using any internet browser, works in four stages. The first step of the integration process is a visit from Smart Warehouse Systems, as the consultant helps to ensure a smooth integration and collaboration with existing computer systems. The aim of the SWS consultant is to conduct a survey and ascertain the requirements of the purchasing company. After the consultation, elaboration of the future system is provided to ensure that parties from both companies understand the needs for future co-operation. The SWS ensures validity of the system in the beginning of installation to avoid expensive changes which would follow the initial installation. The second stage is generating realistic pricing and timescales for process realisation. Specific changes in accordance with company's working practices (such as check digits or bar-code scanners) may be introduced. Without doubt software installation is stage three. During this stage IT personnel from the ordering company and the SWS project manager work together for maximum performance. The last stage of the instalment the smart warehouse software is training.

SWS Aurora has several features stated in their website:

"Multi-user access with multiple languages and full permission management; multiple global warehouses with configurable colour-coded warehouse bays; instant stock summary (how many products are available at any time); historical stock reports; grant access supplier and clients; pessimistic picking; auto-picking by expiry date, ownership, and first-in first-out; configurable dashboard panels and reports"[2].

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[2] The website of Smart Warehouse Systems. Internet access - http://smartwarehouse.com/sws-aurora-web-warehouse-management

Smart Warehouse Systems is not most innovative, but can offer a high-quality performance and convenience for relatively small expenses [2].

1.3 Automated smart warehouses

KIVA systems

One of the most automated warehouses is Amazon warehouse, which was briefly reviewed in the introduction. It uses Kiva's robotic drive units to move the shelves with the required goods around the warehouse territory. As Amazon is a multinational corporation, multiple workers are picking various orders simultaneously. The material handling systems, which Kiva is widely known for, consist of several components: software, robotic drive units (bots) (Fig. 1) and mobile inventory shelves [1]. KIVA systems' description of their solution is truly innovative:

"The complete material handling solution includes work stations configured to fit customer requirements, a wireless network and a server-based back end system. All of these are deployed within a distribution centre and the final pieces are the human operators who pick, pack and ship orders using the automated system. The components are combined to support critical distribution centre operations"[3].

Fig. 1.1 Kivi robotic drive unit [1]

Robotics integrated warehousing

Kiva's concept states, that the required goods "come" to the worker for easier access, yet that is not always possible in a work environment. For the companies, which have bigger commodities to handle, the best possible solution is an industrial robot. As stated in the book *Material Handling Systems: Designing for Safety and Health* by Charles Reese:

"Industrial robots are programmable multifunctional mechanical devices designed to move material, parts, tools, or specialized devices through variable programmed motions to perform a variety of tasks. An industrial robot system includes not only industrial robots but also any devices

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[3] Kiva System Overview. Internet access - http://www.kivasystems.com/about-us-the-kiva-approach/faq/

and/or sensors required for the robot to perform its tasks as well as sequencing or monitoring communication interfaces'[4].

Most commonly robots are used to perform dangerous, often recurrent and uncomfortable tasks. The setup of the robots mostly includes a teach-and-repeat technique, which can be used in a wide variety of fields: material handling, arc or resistance welding, assembly, painting, spraying and even machine-tool load and unload functions [3].

The most suitable industrial robot for the smart warehouse is a loading-unloading robot. Any major company, which has to handle heavy loads usually use one or several robots. They can be used for packaging, loading, sometimes for transferring blanks from one lathe to another. The best suited industrial loading-unloading robot is a heavy-duty payload industrial robot.

The major part of the corporates also refers to heavy duty robots as Titans. KUKA is one of those companies. They have a KUKA robot KR 1000 TITAN F (Fig. 1.2). As the application implies, this robot is perfectly suitable for handling, loading and unloading, packaging and order picking, and other handling operations [4].

Fig. 1.2 KUKA KR 1000 TITAN F industrial robot [4]

This robot is mounted on the floor; it weighs 4700 kilograms and has 6 axes. The payload of this robot is 1000 kilograms. As we know, the goods to be processed are very different in shape and weight, so the program will have to cover the gripper pressure issues.

[4] Charles Reese. Material Handling Systems: Designing for Safety and Health. London, Taylor&Francis, 2000, page 214

Of course, the industrial robot has to be controlled using a controller and a program, which has a pattern of possibilities for the robot to fulfil. It is very important to choose the right controller for this job, in order to achieve the highest efficiency.

The Titan F industrial robot is controlled by the KR C4 controller (Fig. 1.3), produced by the same company. As the company states, this controller is safer and more flexible, has more power and is all in all more ingenious. The concept of the KR C4 controller is innovative and can provide a strong base for the automation of the future by reducing costs of integration, maintenance and servicing. At the same time, efficiency and flexibility of the system are increased. KUKA has developed a new revolutionary, well-designed system which concentrates on international data standards. In this concept, all integrated controllers – from Safety Control, Robot Control, and Motion Control to Logic Control and Process Control – have an adjoining database in which all the intelligent parts exchange information for improved performance [5].

Fig. 1.3 KUKA KR C4 controller [5]

Storage and retrieval systems

Company Swisslog, based in Switzerland, is one of the companies that provide their clients with storage and retrieval systems. There are two different types of these systems: Pallet Handling technology and Case Handling technology. As the aim of this work is to find a way to load the boxes onto required shelves, the brief review of case handling technology is overviewed.

One of the solutions Swisslog introduced is SmartCarrier (Fig. 1.4). This technology is designed for carrying load of relatively small weight and has a really high rate of flexibility. SmartCarrier consists of three components: the rack, high speed double lift and the SmartCarrier itself. This technology is so flexible due to capability of two SmartCarriers move along the rack at the same time. SmartCarriers are powered by super capacitors and the load handling device is integrated in the chassis.

Fig. 1.4 SmartCarrier [6]

The main technical details stated in company's website are:

"Load weight up to 35 kg; SmartCarrier travel speed up to 3 m/s; SmartCarrier travel acceleration 1,5 m/s^2; Lifting speed 6,0 m/s; Lifting acceleration 5,0 m/s^2"[5].

This technology has several benefits for the user: the investment for this technology is not as big as the efficiency, the SmartCarriers don't use a lot of floor-space, the number of SmartCarriers can be easily adjusted to the load of the work, it is energy efficient, has low maintenance costs and reliable operation due to several SmartCarriers per one aisle [6].

AutoStore Small Parts Storage System

AutoStore Small Parts Storage System is a system also manufactured by Swisslog. The purpose of this system is to quickly access small parts or commodities in a single-order picking. The concept of this system is similar to Kiva design as the units approach to the storekeeper: the robots collect bins containing needed parts and brings them to the storekeeper. As described in Swisslog's video presentation, the smart warehouse solution includes bins stacked on one another in a self-supporting grid, which will align the bins and also serve as tracks for AutoStore robots (Fig. 1.5).

Radio-controlled robots handle the bins to and from AutoStore ports. The ports are stations where the bins are taken to and from depending on the assignment. This process is controlled by the warehouse management system which works together with the AutoStore management system for a smoother operation. These programs control AutoStore ports, robots and bins at the real time for a more efficient performance.

[5] Catalogue of Swisslog. Internet access - http://www.swisslog.com/en/Products/WDS/Conveyor-Systems/SmartCarrier

Fig. 1.5 AutoStore robots on a grid [7]

When new commodities arrive in the warehouse, they are transported to a port where the goods are loaded to an empty bin, which are transferred by the robots to a free space in the AutoStore grid.

When a customer places an order, it is processed by the AutoStore control system and the task list is compiled. All the goods are picked according to the list. AutoStore makes sure that the most popular goods are on top of the grid, which makes them easier to pick [7].

Daifuku unit load

Daifuku is a North American company which specialises in material handling systems for nearly a century. The company has a lot of different solutions including a unit load especially made to stack pallets on one another and save as much space as possible.

Daifuku has made a buffer for vertical pallet storage, which maximises the density of the stacked pallets and saves space in the horizontal line. As any other corporation, Daifuku has several different types of unit loading systems adaptable for loads from 500 to 3000 kilograms. The height of the racks can exceed 30 metres (maximum height of the rack can be 36 metres). Although the initial idea of the unit load is to stack pallets, it can also be used to store hazardous materials, bulky items, frozen items etc. This system can operate in -40˚C without excessive noise and, as stated by Daifuku North America, can be configured as double-deep rack unit load system (Fig. 1.6).

According to the company, the unit load system has several advantages, which would make it desirable for the customer: increased floor space, damage control, inventory inspection, higher rates of productivity. Also, this system has high-speed storage operation, replaces old-fashioned storage inventory and can be expanded when needed.

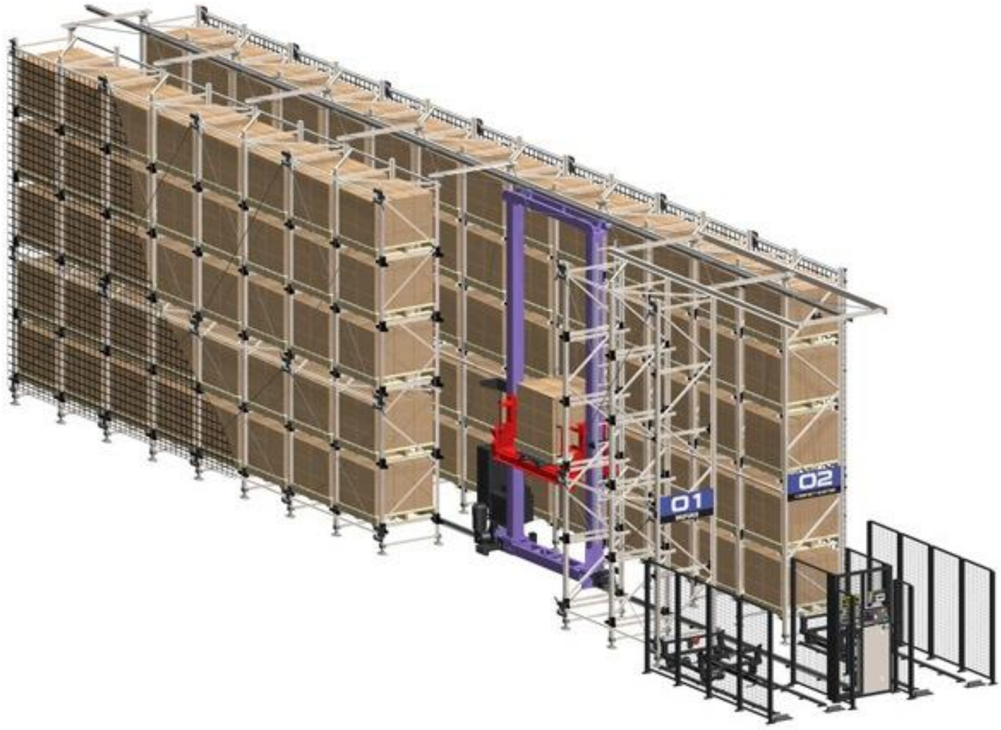

Fig. 1.6 Daifuku unit load [8]

The efficiency of the unit load system depends on the overhead space the warehouse has for installment – the more space, the higher the racks. The length of the rack is also dependant on the warehouse floor space. The speed of given load units highly depends on the size and weight of the load. Knowing these variables, Daifuku can offer, as they call it, single- or double-deep storage or even more than one shuttle. Standard specifications of the system can be modified to any company, but mostly they don‘t change and are presented in Table 1.1.

Table 1.1 Specifications of Daifuku unit load [8]

Load capacity	500 to 3000 kg
Standard height	3-26 m
Horizontal speed	63-250 m/min.
Vertical speed	10-100 m/min.
Shuffle speed	20-80 m/min.
Load dimensions	850-2600 mm x 850-2000 mm

2. DESIGN OF OIL STORAGE

2.1 The assessment of current warehouse situation

The warehouse which is redesigned into smart oil storage belongs to a new founded company named Autepa UAB which is wholesale company importing vehicular, hydraulic and other oil from Germany to Lithuania. The specifics of the work include buying and selling ordered goods. Autepa UAB is in need of a smart warehouse for simpler handling of the production they are importing. The concept is simple: in the area of the warehouse, the shelves and pallets are placed for storing the cartons (boxes) of oil bottles (1 and 5 litres) and the drums of 60 and 208 litres. The drums are transported to the warehouse on the pallets already, so by using a lift it is quite easy to store them wherever needed. The boxes, on the other hand, are the complete opposite. One pallet holds approximately twenty seven boxes of 5-litre bottles and 32 boxes of 1-litre bottles. One box contains four bottles of 5 litres or sixteen bottles of 1 litre, which approximately weighs about twenty kilograms. When boxes have to be stacked on lower shelves, relatively small amount of physical labour is needed (if a warehouse keeper is a man). Unfortunately, when the shelves are two metres high, boxes have to be lifted higher than ergonomic rules would suggest. The best concept for solving this problem is to design a loading-unloading robot. The robot will be designed so that it would move according to the given path for picking up and storing boxes according to the bar code.

2.1.1 The layout of the warehouse

The warehouse is a square area of 1000 m^2 with one main entrance and – as usual in a warehouse – it has no windows (Fig. 2.1).

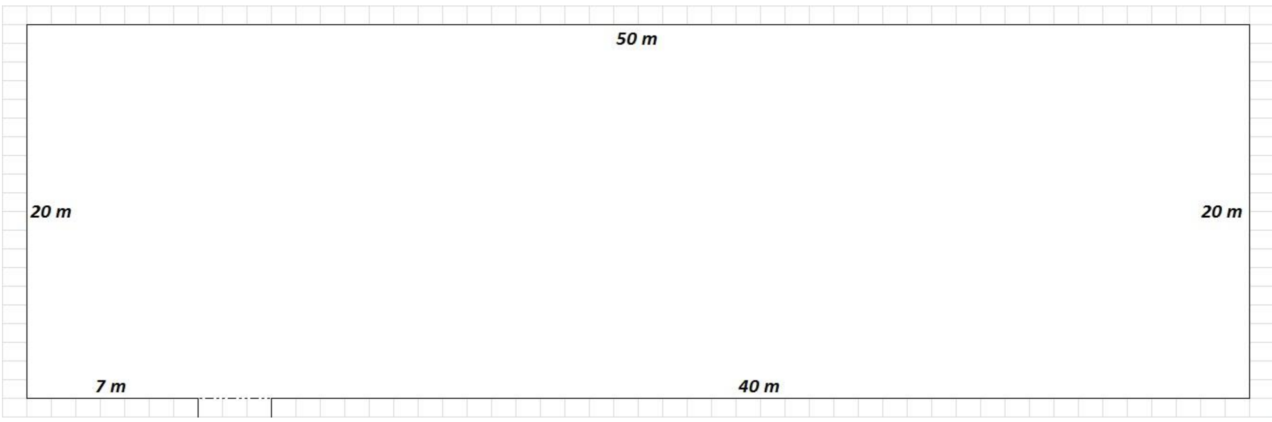

Fig. 2.1 Dimensions of the warehouse

As the boxes have to be stacked on the two-metre-high rack of shelves employing a loading-unloading robot, they are lined in such a way that the robot's path could reach all the cartons stored on the shelves. The dimensions of the racks are – 225x200x100 cm.

The racks chosen for storing oil cartons are The Long-Span 600 racks made by SSI SCHAEFER (Fig. 2.2, a) These racks are very efficient – the shelf adjustability is 50 mm, which assures great utilization of space. Originally the frames supplied can be eleven metres long, beam sizes can be custom-made according to the needs of the customer and the range of shelves is quite big – steel panels, timber panels or even wire mesh decks (Fig. 2.2, b) [9]. One rack customised to meet the requirements of oil storage contains five shelves, each is approximately 50 cm from one another; it is important to note that the first one is 25 cm above the ground and the last one is on the top of the rack. The racks are one metre apart and the shelf is two metres wide.

a) b)

Fig. 2.2 The Long-Span 600 racks: a) view of the shelves; b) possible types of shelves [9]

Currently the warehouse has three different areas: a newly delivered commodities area, a drum storing area and an area for storing boxes. There is some space in the warehouse which could be assigned for the maintenance of loading-unloading robot (Fig. 2.3).

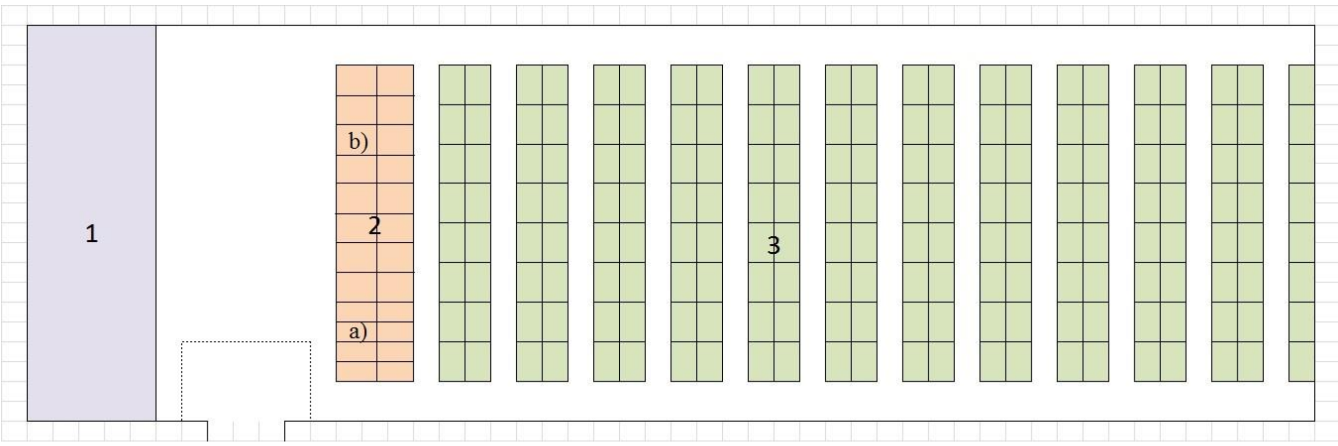

Fig. 2.3 Current layout of the warehouse: 1 – newly delivered commodities area; 2 – a) euro pallet drum storing area, b) industrial pallet drum storing area; 3 – area for storing cartons

2.1.2 Design of warehouse space

The loading-unloading robot is, as mentioned above, designed to unload boxes onto the shelves. The first question that arises is if there is going to be enough space for robot performance. At the moment there is too much space assigned for newly delivered commodities, therefore this space could be divided into three new areas: for loading and charging the robots, and newly delivered commodities.

The scheme shown in Fig. 2.4 presents the layout of the warehouse with robots introduced into daily work of the warehouse. It demonstrates the areas displayed in Fig. 2.3 (newly delivered commodities area, drum storing area and area for storing boxes), but there are two new areas added for robot loading and charging. All five areas are planned in the warehouse in a way to allow two robots to pass each other on their way to the designated shelves.

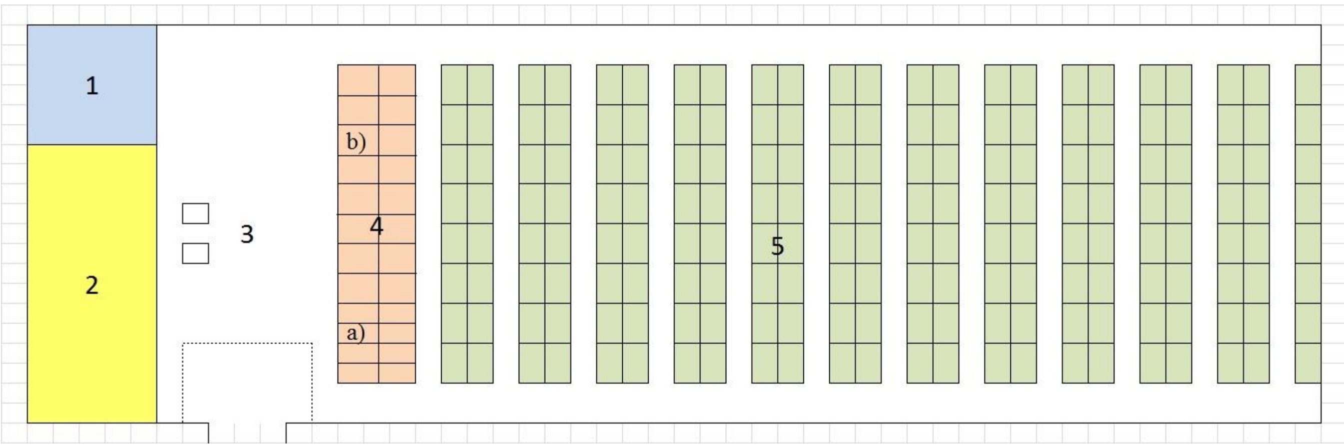

Fig. 2.4 Future layout of the warehouse: 1 – charging area; 2 – newly delivered commodities area; 3 – loading area; 4 – a) euro pallet drum storing area, b) industrial pallet drum storing area; 5 – area for storing cartons

2.1.3 The purpose of the warehouse areas

All five different areas in the warehouse have their specific purpose. The area shown in Fig. 2.4 and labelled as No. 1 is the charging area. According to the future design, loading-unloading robots will operate in the warehouse territory by taking boxes from the loading station and placing them on shelves. In order to do so, robots have to be partially autonomous – they have to move without additional wiring not to cause any inconvenience for the staff and other robots. In order to allow the movement freedom, these robots have to be battery-operated. Depending on a battery type, a robot will be able to operate for some time before being charged, which is the purpose of area No. 1.

Area No. 2 displayed in the Fig. 2.4 is area for newly delivered commodities. When goods are delivered from Germany, Logistics Company unloads them from their truck using a hoist and places them in area No. 2. The pallets with drums are located in the drum storing area by the warehouse keeper using a hoist and the pallets with the boxes are stationed in area No. 2. The boxes arrive on

Euro- or industrial pallets wrapped in a plastic seal, which has to be unsealed by cutting, and then the boxes are placed on the robot.

To facilitate the robot loading process, a new area – loading area – is introduced. As mentioned previously, the boxes have to be taken off the pallet by a warehouse keeper and put on the loading-unloading robot in the most efficient way by loading two boxes at a time. To make this process more convenient for the human, a roller conveyer (or in this particular case two) is introduced (Fig. 2.5). The purpose of the conveyer is simple – the worker takes boxes off the pallet and loads them on the conveyer waiting for the robot to approach. When it arrives, the boxes are pushed on the robot loading-unloading surface and scanned by it to understand which boxes it has to transfer and to what location.

Fig. 2.5 Roller conveyer for the easier robot loading [10]

Areas No. 4 and No. 5 (Fig. 2.4) are self-explanatory as they are made for storing oil in drums and cartons. The box storing area contains eighteen 2-metre high racks. The drum storing area can store two rows of twelve pallets (twenty four in total), one pallet holding four drums of 208 litres or six drums of 60 litres.

2.2 Design of loading-unloading robot

The already planned oil storage layout is proven to be suitable for instalment of the robot. According to the warehouse and its surrounding, the properties of the robot have to be set. The reason loading-unloading robot is required is that commodities have to be raised upwards to a 2 metre height and unloaded. To fulfil this necessity, a robot has to have an unloading platform capable to unload the cartons on the shelf. Furthermore, the most important part of the robot is a lift. It has to be able to move along a predefined path, to have a battery and, most importantly, to be able to elevate to a 2-metre height.

2.2.1 Prototype 1 of the loading-unloading robot

The most convenient lift to use in the loading-unloading robot design is a scissor lift (Fig. 2.6). It takes relatively little space comparing it to a forklift and has a capability to lift the load as high as needed. This part of the robot should be standard lift with a triple scissor mechanism, due to capability to rise to a needed height of 2.25 metres (total of 2.5 metres).

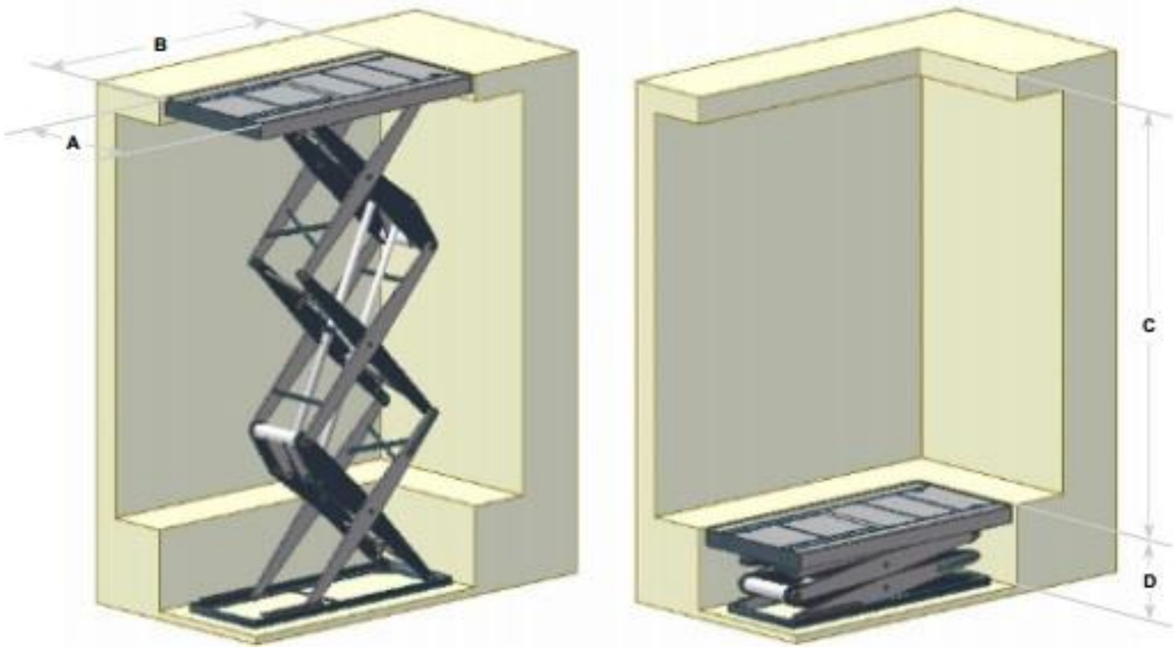

Fig. 2.6 Triple scissor lift ME2XV 05-25 [11]

The scissor lifts are believed to be easy to use; however the construction has its flaws. The scissor lift showed in the Fig. 2.6 is a small-dimensional triple scissor lift introduced by Industry Freixieiro Mechanical Components, Inc., which can escalate up to 2.5 metres [11]. The dimensions of the lift's platform are not big (Table 2.1), which makes it suitable size-wise, however, the dimension of a fully set scissor lift (or in other words – the height of the lift) is 35 cm, which makes the lift too high for the unloading of the cartons on the lowest shelf, which is 25 cm above the ground.

Table 2.1 Dimensions of the triple scissor lift [11]

Model	Load (kg)	Dimensions, mm				Elevation time (s)	Capacity (kW)
		A	B	C	D		
ME2XV 05-25	500	800	1800	2500	350	30	1.5

Nevertheless, scissor lifts are only manufactured as a lifting platform and any additional features would have to be custom-made. For the concept of autonomous unloading robot the lift has to be able to manoeuvre in the warehouse, which means that the scissor lift would have to be adapted for this purpose. The process of fitting the lift to the initial idea would be expensive as it at least has to have wheels, battery and a motor. The assembly of all said parts would have to fit in the design, which takes up a lot of space and the overall height of the lift would increase even more.

The lack of mobility and excessive dimensions of the lift are not the only disadvantages. When the scissor lift has weight on its platform and the weight has to be pushed of it, the construction loses its stability. The biggest problem with the structure of a scissor lift is that the areas of the joints have freedom in order to move smoothly. The lift shown in Fig. 2.6 has three scissors, which gives at least 8 joints. If we add every amount of freedom from ever joint and take into account that at some point in the operation the system will be moving, scissor lift stability is lost. None the less, Triple scissor lift has many constructional components, which are going to be loaded with the unloading panel and cartons. In order to ascertain the strength of the system, buckling study was performed using SolidWorks design program and the results represented in Fig. 2.7.

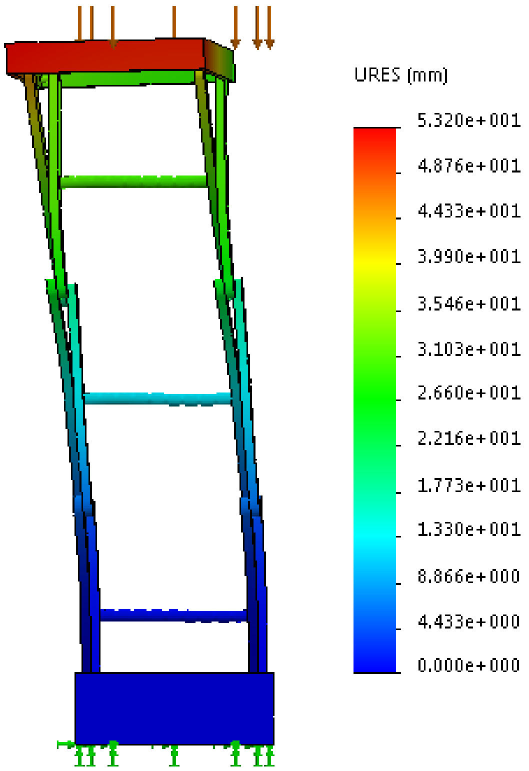

Fig. 2.7 Results of buckling simulation in SolidWorks for scissor lift

In order to implement the study, several features had to be assigned. The system was rigidly fixed on the bottom of the lift, scissor lift was elevated to the maximum required height (2250 mm) and a load of 1000 N was added on the top of the lift. The quantity was chosen due to the possible weight of the unloading platform and the weight of two cartons.

It is visible from Fig. 2.7 that the scissor lift experiences buckling, bends to the side and displacement appears. The magnitude of the displacement is not very significant – 53.2 mm, but over time, buckling will cause joints to fail and the system will break.

2.2.2 Prototype 2 of the loading-unloading robot

The second type of lift available for the design of loading-unloading robot is an electric forklift. This type of lift has wheels, motor and a battery, which already is more efficient than the scissor lift. The best choice for a scissor lift is an electric ATLET forklift H3590 (Fig. 2.8).

Fig. 2.8 Electric forklift [12]

The forklift shown in Fig. 2.8 is easily operated, suitable for order picking and commodity lifting. This lift can elevate to an approximate height of 3.5 metres and, as mentioned by the manufacturing company, is ideally suitable for lifting the goods in smaller indoor spaces. This forklift has alternating current motor, which makes it safe to use, energy efficient and powerful for the task it's designed. The initial properties of the ATLET forklift are given in Table 2.2. The overall specifications are presented in Appendix 1.

Table 2.2 Properties of ATLET forklift H3590 [12]

Lifting motor capacity	2.2 kW
Operating motor type	AC
Operating motor capacity	1.3 kW
Lifting height	3590 mm
Length of the forks	1200 mm
Width of the lift	800 mm
Battery voltage	24 V
Battery operation time	230 Ah
Charger voltage	24 V

It is clear, that electric forklift ATLET H3590 is designed for human use; however the concept of the loading-unloading robot states, that the robot should be able to move on its own. In order to accomplish the said task, it is necessary to process the lift into a robot. The advantage of a forklift in this situation is that it already has a motor, wheels, battery and all the wiring in its construction [12]. The main alternation, which has to be made, is to withdraw the handle and include a controller into the design (Fig. 2.9).

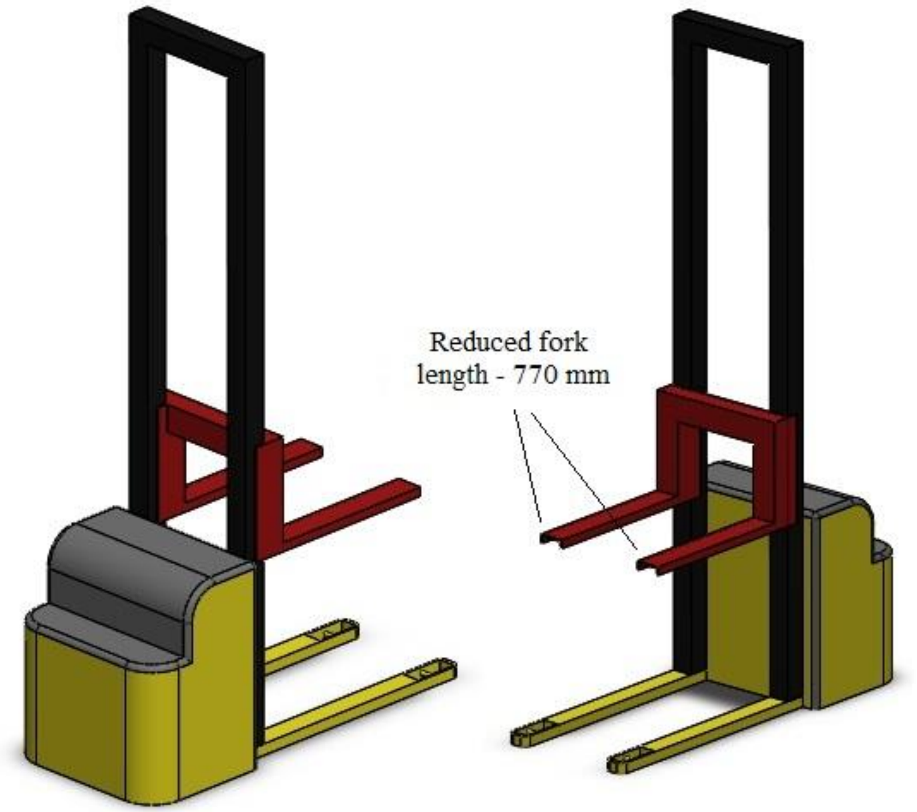

Fig. 2.9 Concept of an electric forklift

The converted electric lift shown in the Fig. 2.9 is also redesigned to fit the requirements of the warehouse. Originally the forks of the lift are 1200 mm, but this length is too big and unnecessary for the unloading platform. That is why the lower forks, which have to support the robot remains 1200 mm long for the instalment of the more suitable wheels and the forks which will carry the unloading platform are shortened to 770 millimetres.

To ensure, that the electric lift is a better choice for the unloading robot than the scissor lift, the same buckling SolidWorks simulation was performed. The forklift was loaded with the same force, yet a platform was added on the forks to avoid concentrated force on the forks of the lift, because the load will be distributed on the unloading platform, not just on the forks. The same features were taken – rigid fixing on the bottom of the forklift, the forks elevated to maximum height of 2250 mm and the force given to the platform – 1000 N. The results obtained during the simulation are shown in Fig. 2.10.

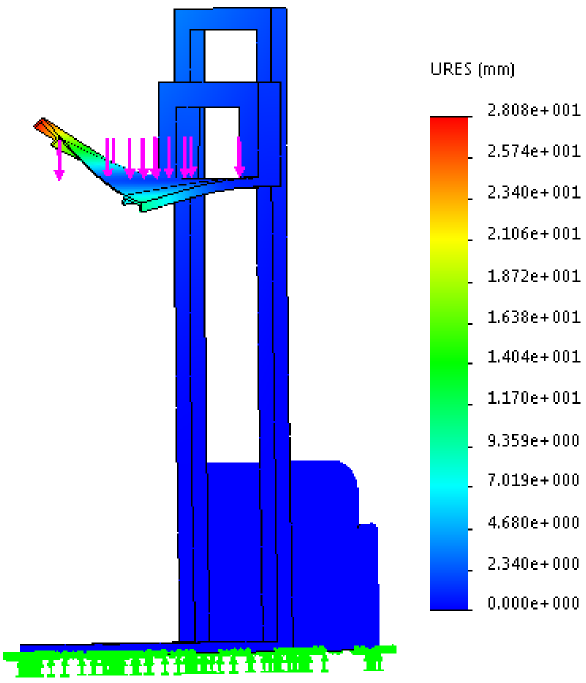

Fig. 2.10 Results of buckling simulation in SolidWorks for forklift

It is visible that deformation appears, although the deformation presented in Fig. 2.10 is hyperbolised; the true deformation is hardly visible. If the results were compared with the ones received in simulation on the scissor lift, the quantity is a lot smaller – 28.08 mm. These simulations are performed under perfect conditions, therefore are not completely accurate. Nevertheless, the displacement of the forklift is 1.9 times smaller than the displacement of the scissor lift. Furthermore, the company AJ Produktai is stating in their website, that the forklift ATLET is capable to lift a load of 1250 kg if the height to which a load has to be elevated does not exceed 2500 mm [12].

Taking the above-mentioned information into account, it is clear, that the electric forklift is in fact a better choice for designing loading-unloading robot. The advantages are simple, but highly important: lower buckling deformation; motor, battery and wheels originally added to the design and steadier mechanism.

2.2.3 Selection of the robot wheels

The loading-unloading robot designed using an electric forklift will have to move according to a predefined path as it was mentioned before. In order to save warehouse space, the radius of the robot turn has to be minimized as much as possible. In the primary scheme of the forklift (Fig. 2.8), simple Vulkollan wheels are included, but using the original wheels the radius of a turn is quite large.

In order to make the robot more agile, omni-directional wheels have to be added to the project. The biggest advantage of the omni-directional wheels is that a vehicle (or a robot) with these wheels can not only move forward and backwards, but also are able to move left and right without actually turning. This phenomenon is achieved using the special design of the wheels – the rollers on the wheel are rotated in 45 degrees. When the different wheels turn in different directions, e.g. rear and front wheels, the vehicle is "sliding" to the side. Omni-directional wheels help eliminate any space leftover for the turning radius.

In order to choose the right omni-directional wheel, the mass of the forklift has to be determined; mass of the unloading mechanism has to be estimated and mass of the load (the cartons) has to be added together. The required information is presented in Table 2.3.

Table 2.3 The weights of the robot components

Name of the component	Weight, kg
Electric forklift, m_{EF}	450 kg
Unloading platform, m_{UP}	50 kg
Load (two oil cartons), m_L	40 kg

The overall weight of the robot, which is going to press the wheels, is calculated as follows:

$$m = m_{EF} + m_{UP} + m_L \tag{2.1}$$

The overall weight m is calculated and the result obtained is m = 540 kg

Taking in account the obtained weight of the robot (540 kg), heavy duty wheels have to be chosen. For the purpose of moving in the warehouse area, heavy duty steel Mecanum wheels (Fig. 2.11) are ideally suitable for the design of the adjusted forklift, because load per wheel is 150 kg, which makes a total load possible of 600 kg.

In order to achieve maximum performance the set of four wheels have to added to the design. One set include two right and two left wheels. The wheel is 203 mm in diameter and has twelve nylon rollers. The rollers are rotated in 45 degrees angle to the initial axis of the main wheel.

These wheels allow the robot to move forward and backwards, and sideways as well. The load which can be carried by the Mecanum wheels is more than 150 kg, which is enough for the loading-unloading robot [13].

2.2.4 Design of unloading platform

The lift itself is not enough for a full unloading of the goods. For that purpose it is necessary to design an unloading mechanism, which would be capable to push of the boxes onto the shelf when the lift goes up to the needed height. One of the most important features the unloading platform has to have is capability to operate multi-directionally. This capability is only available for some types of conveyors. The mechanism shown in Fig. 2.11 operates to two directions – it can unload the boxes to the left- and right-hand side. This feature saves space and assures that no structural fractures occur. The accurate dimensions of the conveyor panel are given in Appendix 2.

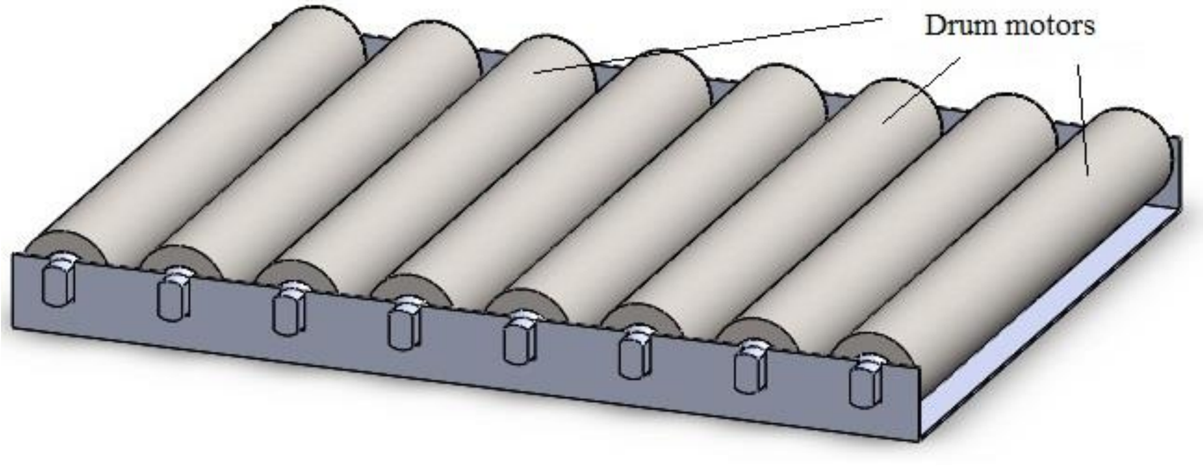

Fig. 2.11 Conveyor panel

The best choice for engineering the conveyor panel is a drum motor. The company Interroll AG has introduced a drum motor perfectly suitable for unloading robot design. Interroll introduced a reliable, drum motor with zero maintenance, low noise and really lightweight. Interroll drum motor 80i is an asynchronous squirrel cage AC 3-phase motor (Fig. 2.12) [14]. Specifications of the drum motor are represented in Appendix 3.

Fig. 2.12 Interroll 80i drum motor [14]

Originally the voltage of the drum motor is 230/400 V, but the most international voltages can be supplied if requested; along with the size of the shell. The dimensions and specifications of the unloading platform have to meet the requirements of the forklift design. Taking in account this information, specifications of the drum motor are presented in Table 2.4.

Table 2.4 Specifications of drum motor 80i [14]

Voltage	24 V
Frequency	50 Hz
Ambient temperature	+5 to +40 ˚C
Shell length	600 mm
Drum motor material	Stainless steel

The voltage of the drum motor is chosen to be 24 V because it is the same as the lift's battery. The length of the shell is 600 mm, so it would be suitable for the cartons to fit with added allowance. The voltages in which the drum motors and the forklift operate are the same, so no additional converters are needed for the design.

After all the specifications are set, it is necessary to calculate the time in which the cartons will be pushed of the conveyor. This is important for estimated time of unloading process to be determined. This is performed to know the time a storekeeper has to prepare another load. All the information required for this calculation is presented in Table 2.5.

Table 2.5 Mechanical data for the drum motor 80i [14]

P_N, kW	i	v, m/s	n_A, min^{-1}	M_A, Nm	SL, mm
0.058	31.09	0.179	42.10	12.40	600

Here: P_N is rated power, i is gear ratio, v is velocity of the shell, n_A are rated revolutions of the drum shell, M_A is torque of drum motor and *SL* is length of the shell.

In order to calculate the time in which the cartons are pushed of the unloading panel it is necessary to know the length of the panel. The drum motor shell length is 600 mm and the panel contains 8 drum motors for application in unloading two boxes at a time. The length of the whole unloading panel is 806 mm (Fig. 2.13). The velocity of the drum motors is presented in Table 2.5 and is 0.179 m/s.

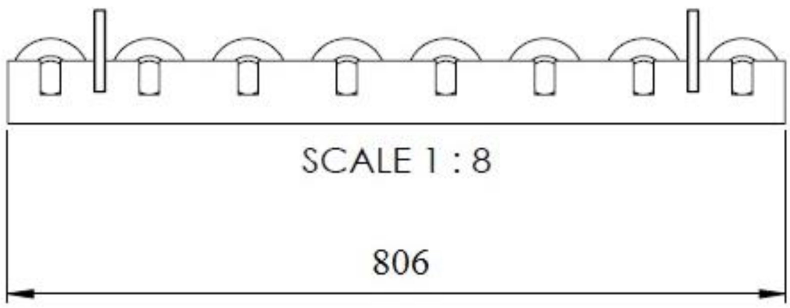

Fig. 2.13 Length of the unloading panel

Knowing this information it is possible to calculate the time in which cartons are pushed on the shelf. The distance, which has to be travelled by the boxes, is divided by the velocity and the unloading time numerable is 4.5 seconds.

2.2.5 Finished design of loading-unloading robot

After all the mechanical features are selected they are composed together and the loading-unloading robot is created (Fig. 2.14). It is necessary to acknowledge that the robot will have several different sensors and controller so it could operate by oneself. In order to fit the wiring for these sensors and the unloading platform, the robot will have all the wiring covered in the box on the lifting mechanism and inside the lift’s body.

In order for the robot to comprehend which cartons it’s transporting and by which rack it has to stop bar code scanners have to be mounted on both sides of the robot. The design of the robot enables the bar-code scanners to be mounted on the bottom of the bed of the conveyor panel after they are chosen. The scanners will also be wired to the box on the lift and powered by the forklift battery.

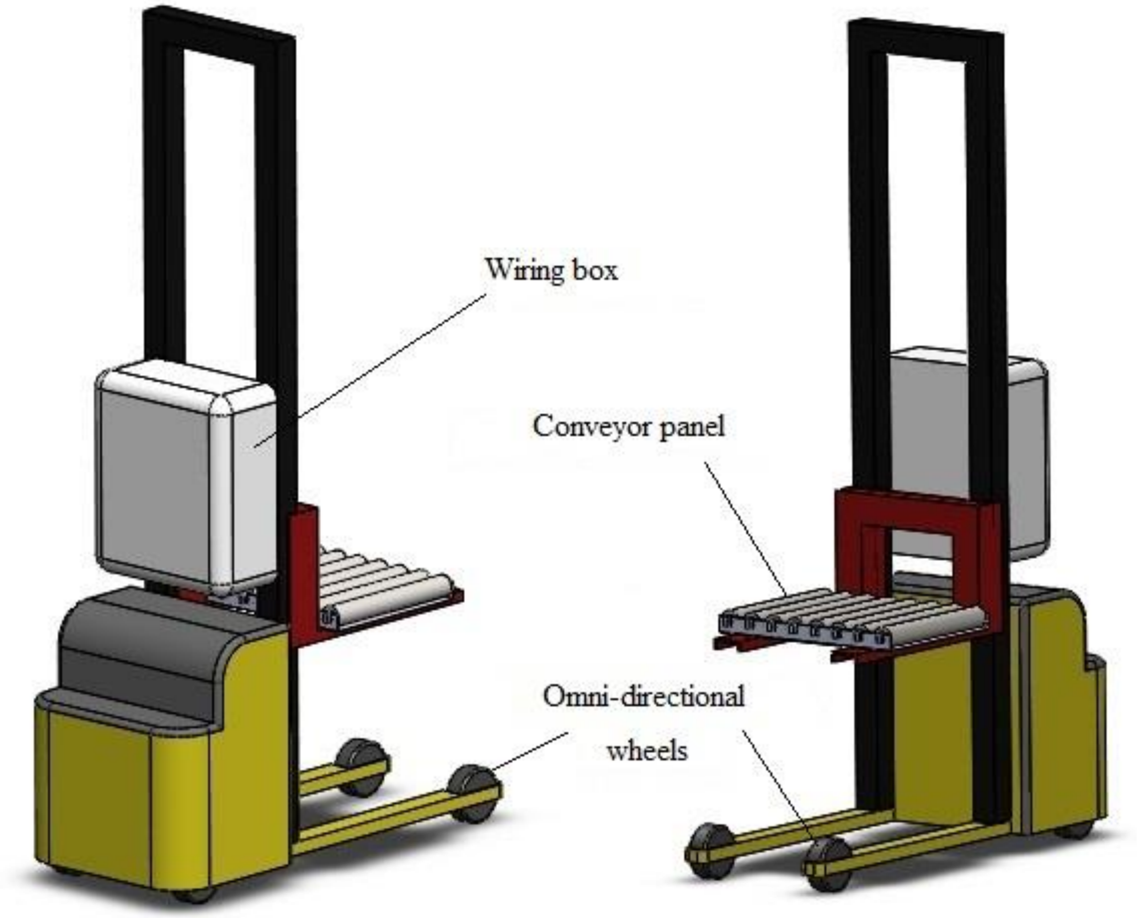

Fig. 2.14 Loading-unloading robot

In order for the robot to comprehend which cartons it's transporting and by which rack it has to stop bar code scanners have to be mounted on both sides of the robot. The design of the robot enables the bar-code scanners to be mounted on the bottom of the bed of the conveyor panel after they are chosen. The scanners will also be wired to the box on the lift and powered by the forklift battery.

The final design of the loading-unloading robot is going to be autonomous with the possibility to unload two cartons of oil bottles at a time and going to move along a path integrated into the warehouse. The sensor to implement this task is going to be mounted on the body of the lift, depending on the type chosen. Optical sensors will also have to be added to the design in order for the robot to understand if the boxes are on the unloading conveyor or they are already pushed of.

3. CONTROL OF THE OIL STORAGE

3.1 Loading-unloading robot control

The loading-unloading robot is an autonomous robot, which is going to move along a path to fulfil a loading-unloading operation. The loading-unloading process will start with the storekeeper, unsealing the newly received goods from the pallet (Euro or industrial). The warehouse in Austria loads all the ordered goods on pallets after the order is made. The drums of 60 litres are loaded on one pallet, drums of 208 litres – on another. The boxes are loaded on another pallet which may contain cartons of various types of oil, which have barcodes on them. When the pallet with cartons arrives in the warehouse, the job of the storekeeper is to cut the pallet out from the plastic seal and collect two boxes with the same type of oil in them. The boxes then are loaded on the manual conveyor, to make it easier to unload on the robot, as well as easier for the robot to scan the barcodes. The loading-unloading robot comes to the loading area, scans the barcode on the box and the cartons are unloaded on the robot by the storekeeper. After this process, manual work ends and the controller should begin the autonomous process of unloading the boxes. According to programing, the robot goes to the required rack tracking a predefined path, stops at this rack and scans the barcode on the rack, to make sure it arrived at a needed location. The lift then escalates to a shelf, which contains the cartons of the same origin as the ones on the unloading panel. The robot scans a bar code on the shelf again to make sure that the right shelf is chosen. The unloading panel then unloads the boxes and the robot returns to the loading station. This process is shown in Fig. 3.1.

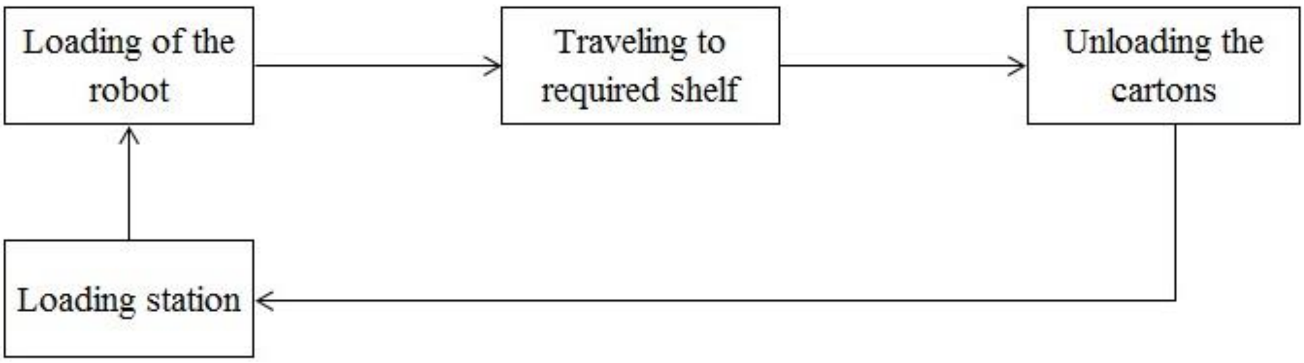

Fig. 3.1 Block scheme of the loading-unloading process

For correct selection of required elements to fulfil the loading-unloading operation the control algorithm is designed (Fig. 3.2). All the processes including inside logistics, barcode scanning and loading-unloading operation are included in the algorithm in order to gain better understanding about the required elements of robot control.

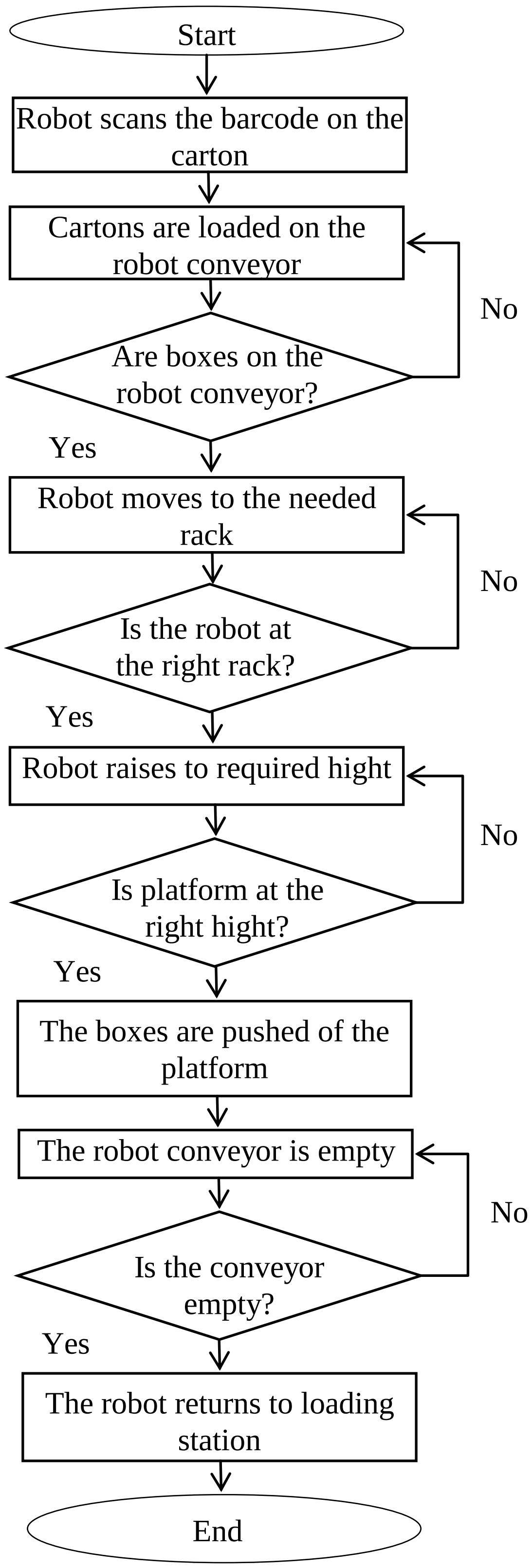

Fig. 3.2 Loading-unloading robot control algorith

3.2 Control elements of the robot

In order to fulfil the control algorithm shown in the Fig. 3.2 a series of sensors has to be chosen. The sensors have to be picked out according to the layout requirements and the design of the robot.

3.2.1 Placement positioning systems

Positioning sensors, as the name suggests, are suited for the determination of the position the required unit is at. The positioning sensors which are going to be included in the design are designated to indicate the type of the cartons the robot is handling and the assigned rack and shelf for the placement of the cartons mentioned above. Different types of cartons (containing different types of oil) are going to be stored on different shelves. The program, which is going to handle the loading-unloading operations will have the layout included in the program and will be tracking the pre-determined path that the controller will receive after the bar-code on the box is scanned using a bar-code scanner.

Fig. 3.3 Mabanol Engine Coolant Premium barcode on the carton

As we can see in Fig. 3.3, a bar code on the Mabanol carton consists of several black and white stripes. When the bar-code scanner shines a certain light on the bar code, the retrieval of the data contained in the bar code is achieved. The bar code scanner records the light which reflects from the code and replaces the stripes with binary digital signals; the reflections are weaker in black areas and stronger in white ones. Analog waveforms are generated from the reflections received by the bar code scanner. After obtaining the analog signal, A/D converter converts it to a digital signal. After all obtained data is processed, the required information is received (Fig. 3.4) [15].

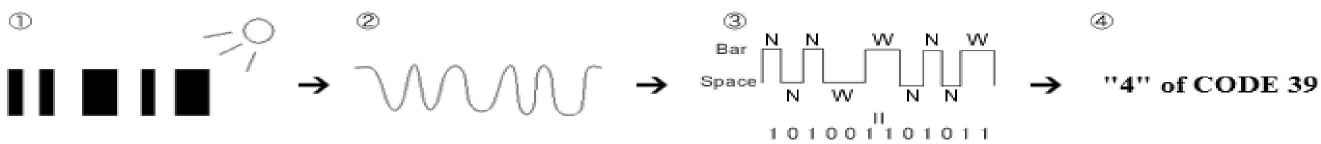

Fig. 3.4 Principle of bar code reading [15]

CCD bar code scanner

„CCD (Charge Coupled Device) Barcode Scanner use an imaging CCD (similar to the ones found in digital cameras) to take a picture of barcodes which are then decoded into a sequence of characters. CCD Barcode Scanners have a very fast scan speed, but a low scan range (often less than 8 centimetres from the barcode). CCD Barcode Scanner can be very durable because they do not contain any moving parts, but are limited because they cannot read any barcodes wider than the imaging element. Their low cost and speed make CCD Barcode Scanner well suited for point of sale applications, but their short read range makes them a poor choice for warehouse or industrial applications.“[6] – states the Barcodes Inc. [16].

One of the Barcode Scanners the mentioned above company produces is Unitech MS910-CUBB00-SG Barcode Scanner. The MS910 is a relatively small, compact barcode reader, which is perfect for a manual use in package delivery or hand picking of goods. Simplicity and wireless technology combine together and produce a very convenient bar code scanning by a push of a button (Fig. 3.5).

Fig. 3.5 Unitech MS910-CUBB00-SG Barcode Scanner [17]

Table 3.1 Specifications of Unitech MS910-CUBB00-SG Barcode Scanner [17]

Scan rate	240 times per second
Operation voltage	3.7 V CD
Interface	Mini USB
Maximum scanning distance	185 mm
Power supply	Lithium-ion battery

The power type used by the CCD barcode scanner is CD, but AC power adapter might be added. The biggest flaw this scanner has is that the maximum scanning distance is 185 mm, which is not enough for the warehouse application [17].

[6] Catalogue of Barcodes Inc. CCD Barcode Scanner. Online access - http://www. barcodesinc.com/cats/barcode-scanners/ccd.htm

Laser bar code scanner

Laser Barcode Scanners is the most common type of barcode scanners used in various work places. The biggest advantage the laser scanner has is that it doesn't have to be in contact with the barcode to be read. A standard-range laser bar code scanner can read a barcode from about 15 to 60 centimetres away. The standard scanners are not the only ones in the market, long-range scanners are also available and their scan range is approximately 60 to 240 centimetres away. It is possible to find an extra long-range scanner which is capable of reading a barcode which is about 9 metres away. Laser barcode scanners are usually produced as "gun" scanners and are held in hand, however, they can also be built in counter-tops or just plainly fixed-mounted.

The laser barcode scanner which would be suitable for our loading-unloading robot is the Datalogic DS2400N-2K Series (Fig. 3.6). The specifications are presented in Table 3.2.

Table 3.2 Specifications of Datalogic DS2400N-2K Series [18]

Scan rate	up to 5 mils
Operation voltage	10-30 V CD
Interface	EtherNet/IP, Ethernet TCP/IP and PROFINET
Maximum scanning distance	600 mm

This laser scanner has a really good connectivity freedom, high optic performance and various applications can be included depending on the place of usage – shop floor, OEM machinery or a warehouse. [18].

Fig. 3.6 Datalogic DS2400N-2K Series laser barcode scanner [18]

As stated in Datalogic website, the above-mentioned laser scanner is ideally suited for automatic warehousing applications, relatively small conveyors, tracking and picking commodities, and even for document handling. Furthermore, the scanner has capability to read low quality or even damaged barcodes, which is perfect in oil storage, because the cartons may not arrive in perfect shape [18].

Considering all the aforementioned information, the discussed barcode scanners are quite different in function. First of all, Unitech MS910-CUBB00-SG CCD Barcode Scanner has a very fast scan speed, but a low scan range (mostly up to 80 mm), while Datalogic laser scanner DS2400N has a wide scan range (600 mm) and may not be in contact with the label. The latter feature is one of the most important when choosing a barcode scanner for industrial applications. None the less, DS2400N has various adaptable communication protocols that will make it simple to combine with the remaining design. For all the reasons listed above, the barcode scanners chosen for the loading-unloading robot are laser scanners DS2400N-2K Series, specifications presented in Appendix 4. They are going to be mounted on both sides of the conveyor panel (Fig. 3.7).

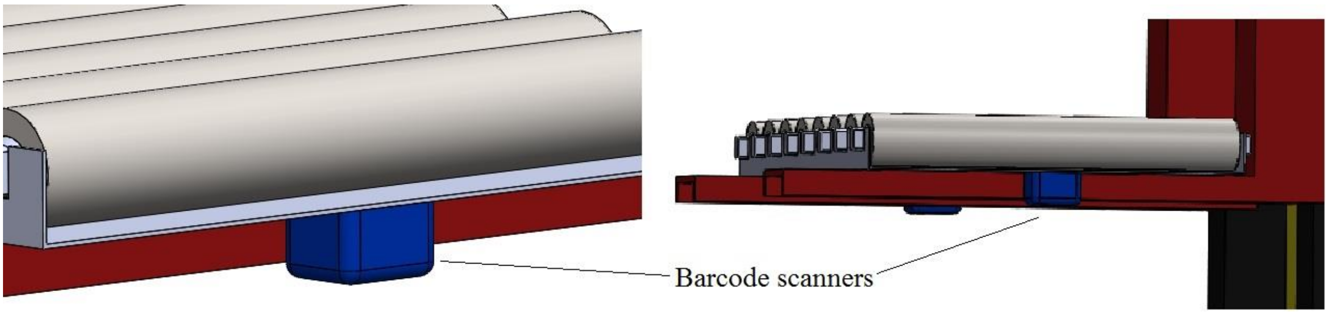

Fig. 3.7 Barcode scanners mounted on the robot

3.2.2 Itinerancy systems

As mentioned in the initial design of the loading-unloading robot, it is going to be an autonomous robot, which will be able to travel a given path in order to fulfil an unloading operation. In order to control the movement of the robot, a path has to be determined before introducing the robot to the work environment. It is very important to accommodate the path of the robot with the existing layout of the warehouse.

The warehouse layout is designed so the robot would be able to pass the racks, but no excess space would be left. Also, the robot will always enter the storage area No. 5 (Fig. 3.8) through one side and exit through the other. This helps avoid collision if two robots are introduced to the work environment.

Most common tracking systems used in the warehouses are guide rails. Unfortunately, as small manually-handled fork lifts will be used for pallet handling, the rails will be inconvenient. Despite the guide rail systems, there are other widely popular systems used in warehousing for path tracking, such as inductive sensors and photo sensors.

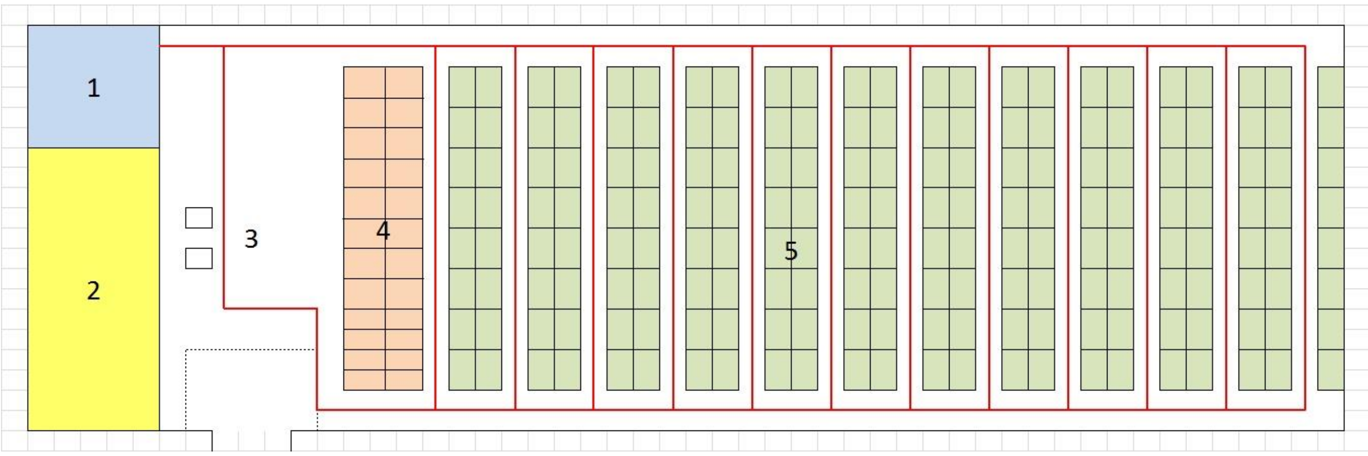

Fig. 3.8 Warehouse layout with the travel path marked with the red line

Inductive tracking systems

The main purpose of inductive tracking system is to enable any autonomous vehicle to move along a path of inductive current. If the comparison of inductive and optical track guidance would be performed, the main difference would appear – the inductive method is not responsive to dirt, oil or other substances found on a warehouse floor, while the optical tracking has to follow a bright line and every interfering spot would cause a vehicle malfunction. Considering this information, inductive tracking systems have gained the trust of various industries for applications in plants, warehouses or manufacturing facilities. The system is beneficial for any user because a wide selection of frequencies and currents, as well as heights from guide conductors can be programmed.

Fig. 3.9 Standard Guidance Sensor HG 19330 [20]

The manufacturers of tracking systems have highly increased their performance by including a microcomputer into the design of the sensor, which results in ease of use and augmentation of the output performance. These track guidance systems are most commonly used in industrial companies for their inside transportation. Inductive track guidance systems are also used for public transport, collision test cars or specialised vehicles [19].

German company Götting KG has a standard inductive tracking sensor HG 19330 (Fig. 3.9) which could be used in oil storage. The HG 19330 is not expensive and it detects horizontal and linear components using a cross coil system. The difference of the signal is measured when the output voltage is proportional to the vertical field lines. When the distance between the sensor and the wire and the wire current are constant, this output is valid.

The inductive tracking sensor HG 19330 gives the user a possibility to choose a required frequency out of eight listed in the System Description, and the distance of the sensor from the track wire. Furthermore, the sensor calculates the sum voltage that meets the horizontal components. When the voltage sum is below the computational value, the output becomes zero, which is the basis of the guide wire detection [20].

The inductive tracking system would not be complete without the guide wire. The laying of the wire for inductive tracking has to be performed very accurately. Götting KG claims that it is necessary to use an insulated copper strand. The cross section of this strand should not be less than 1.5 mm^2. For premises subjected to higher mechanical stress 2.5 or even 4 mm^2 crosscut wire is recommended. The wire has to be placed in a slot wide enough for the wire to fit in, adding an allowance of 1 mm to the diameter of the strand. It is very important to install the cable into the slot straight-lined and avoid 90˚ turns. The corner cut should be about 45˚. The slots have to be vacuum cleaned before laying the wire in order to evade scathe caused by cement dust or gravel. If water is used in the cleaning process, the slots have to be dried before installing the cables. The compound used for the sealing of the slots has to be matching with the original soil [21].

The guide wire and the tracking sensor are not the only equipment needed for a full operation of inductive track guidance. As shown in Fig. 3.10, a frequency generator is necessary for the system to operate.

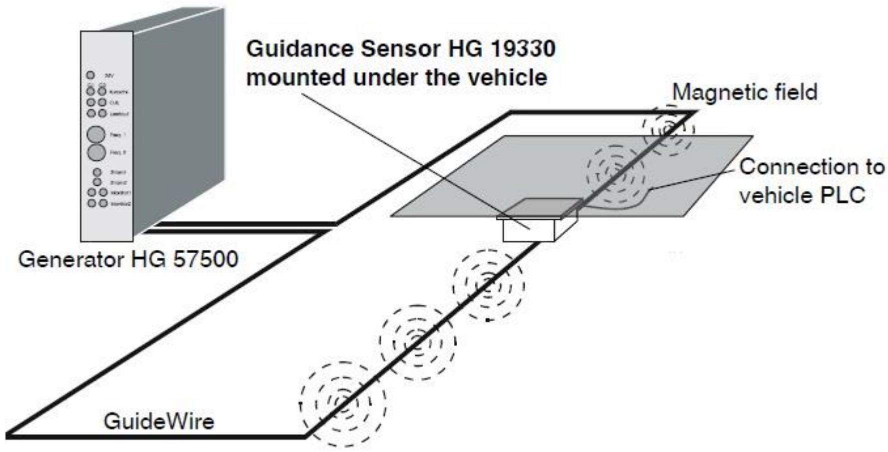

Fig. 3.10 Inductive tracking system [20]

Fig. 3.9 shows that the manufacturer of the guidance sensor HG 19330 offers a generator HG 57500 (Fig. 3.11) for the application in the finished inductive guidance system. This generator induces

AC current for track guiding. As described in the data sheet of the frequency generator, it produces current in a conductive loop. This generator uses Class-D power amplifier which results in high efficiency of the system.

Fig. 3.11 Frequency generator HG 57500 [22]

If malfunction of some kind appears during the running of the system, all information is indicated on an LCD screen on the front panel of the generator. The said generator is compact, cleanly built, and inexpensive and goes well with the guidance sensor HG 19330 [23].

Optical tracking systems

Another tracking system available for employment in the warehouse is optical line tracking system. The said system is based on tracking a line, which is really easy to apply; prior to a guide wire. The predetermined track is recognised using modern technology – tracking cameras and image processing systems. Various systems are created which can operate even if the line has interruptions and doesn't see it as an obstacle. The modern technology has developed the ability to identify coded tracks or optical markers [24].

Fig. 3.12 Optical Line Tracker HG 73840 [25]

Götting KG represents not only inductive tracking systems, but also optical line trackers. One of the line trackers (interpreting units) the company suggests is HG 73840 (Fig. 3.12).

This sensor is a part of an Optical Guidance System (OGS) for Automated Guided Vehicles, which would be the loading-unloading robot. OGS gives a vehicle or a robot opportunity to travel along a contrast line which is indicated on the ground. The optical tracker HG 73840 perceives the location of the guiding line through the camera and the view it recorded. The sensor outputs the position of the line with respect to the centre of the taken picture.

Furthermore, the sensor has a capability to detect ramifications from the original course. The optical tracker also has the ability to comprehend information from two PAL standard video cameras. They have a combined signal in order to guide the robot to two different directions e.g. forwards and backwards [25].

The line tracker HG73840 is paired with a HG 73841 optical camera (Fig. 3.13). This camera is a part of an Optical Guidance System for Automated Guided Vehicles as described in Götting KG website. This camera fixates a view and guides a vehicle along a contrast line [26].

Fig. 3.13 Camera HG 73841 [26]

The most important feature for the optical tracking system to operate successfully is the contrast of the line with the surrounding environment. If the difference is distinctly visible, the tracking system is going to work without any interference. Nevertheless, the tracking system is able to “fill” a temporary gap due to integrated filters, which depends on the velocity of the robot and the size of the gap. Light reflections and shades may have substantial impact on the system‘s performance as well, as the track recognition may be compromised. Optical track guidance can only be used in relatively clean premises, due to possible impairment of the performance [25].

The mounting of the camera is very important (Fig. 3.14). If camera’s not connected correctly, it might cause offset errors. The mounting should let the camera to pivot a little – about ±3˚ [26].

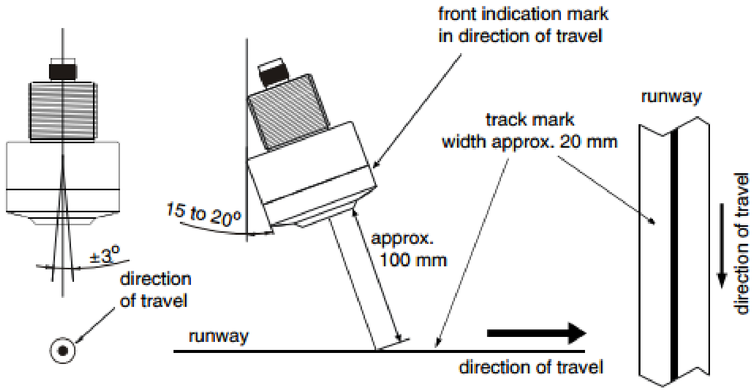

Fig. 3.14 Mounting of the optical camera [26]

Theoretically both tracking systems are suitable for oil storage applications. However, the manufacturer of the tracking systems has mentioned that the inductive tracking system is more suitable for industrial applications and is ideally fit for instalment in a warehouse. The optical tracking system is unreliable in this line of work, because it may react to dust, dirt or even tire marks. The storekeepers use manual pallet lifts, which may leave said marks or even disturb the guide line. Taking above-mentioned reasons into account, the chosen tracking system to install in the oil storage is inductive tracking system. The specifications of the sensor and generator are represented in Appendix 5 and Appendix 6.

The inductive sensor has to be fairly close to the guide line; therefore the sensor is going to be mounted on the base of the body. In order to ensure accurate path and clean turns, the sensor is mounted on the centre of the body (Fig. 3.15).

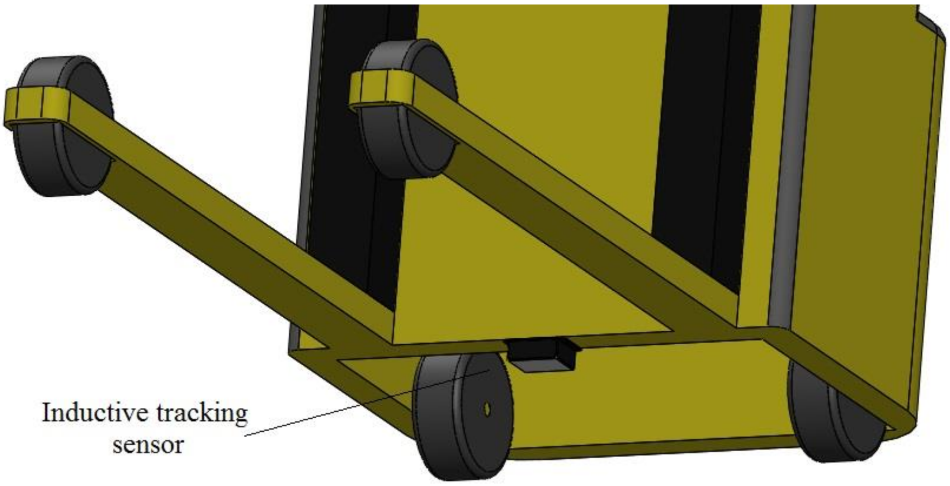

Fig. 3.15 The inductive tracking sensor

3.2.3 Loading-unloading operation system

During the loading-unloading operation, the robot has to understand if the cartons are already on the unloading conveyor and if the cartons are already unloaded on the shelves. The unloading conveyor is going to be programmed to unload the cartons on the required shelf by operating for a predetermined amount of time. Nevertheless, there has to be simple ways to make sure no cartons are left on the conveyor, as well as knowing if the cartons are loaded on the conveyor by the storekeeper. The best sensors suited for this application are thru-beam optical sensors.

Thru-beam optical sensors have a transmitter and receiver. These parts of the sensors are housed in different casings so that they could be operating separately. The principle of the thru-beam sensor is simple – receiver is a recipient of the beam emitted by the transmitter (Fig. 3.16) and when the light beam is interrupted by an object – the oil cartons – the voltage in the receiver decreases and initiates the switching function. These kinds of sensors are most commonly used in packaging line monitoring, but are also perfectly suitable for the supervision of the carton unloading operation [27].

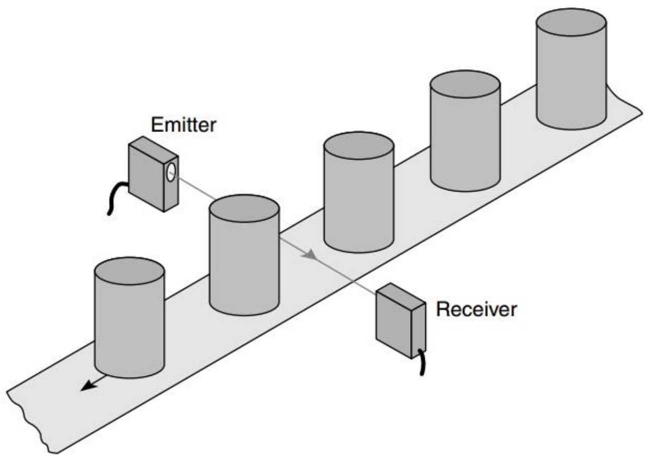

Fig. 3.16 Thru-beam sensor in process [27]

A thru-beam sensor, which would fit the requirements, is ML30-P/25/102/115 produced by the Pepperl-Fuchs (Fig. 3.17). This sensor has an effective detection range of up to 6 metres, IRED light source, simple installation, NPN output and – most importantly – has an operating voltage of about 10 to 30 V DC [28]. Overall specifications are presented in Appendix 7. The type of voltage is of course not in line with the other equipment; however it is really simple to use a DC-AC converter to adapt the optical sensors to the remaining system.

Fig. 3.17 ML30-P/25/102/115 thru-beam optical sensor [28]

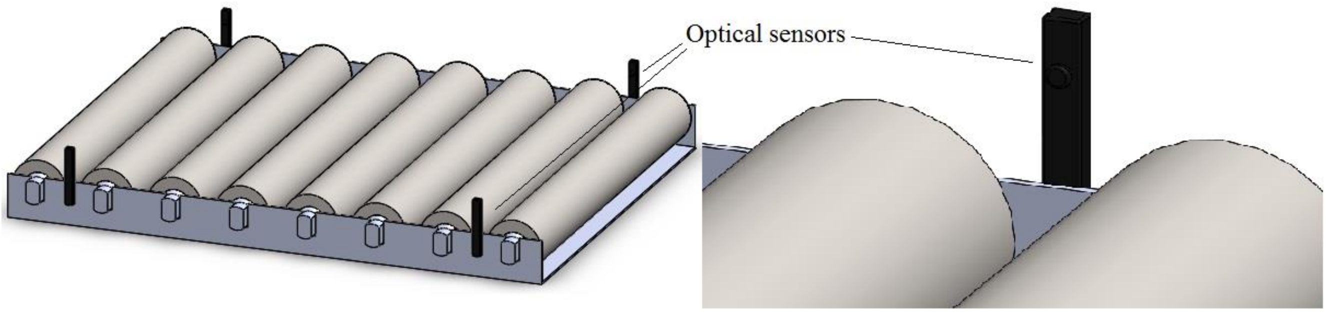

Fig. 3.18 Thru-beam optical sensors mounted on the unloading conveyor

The above-mentioned thru-beam sensors are going to be mounted on both ends of the unloading conveyor, because the conveyor can unload the cartons on the shelves located on both sides of the conveyor. The sensors are mounted in a manner which will not interfere with the operational requirements and will fulfil the assigned task (Fig. 3.18).

3.2.4 Control of the elements

All the elements of the robot have to be controlled by a microcontroller according to the task which is programed into the computer. All the sensors activate a specific part of the robot to fulfil the task of unloading the cartons of oil. The structural scheme of control unloading operation of the robot is created (Fig. 3.19). The scheme shows how, according to the signals obtained from several sensors, the motor of electric fork-lift, motor of the lift and drum motors are controlled.

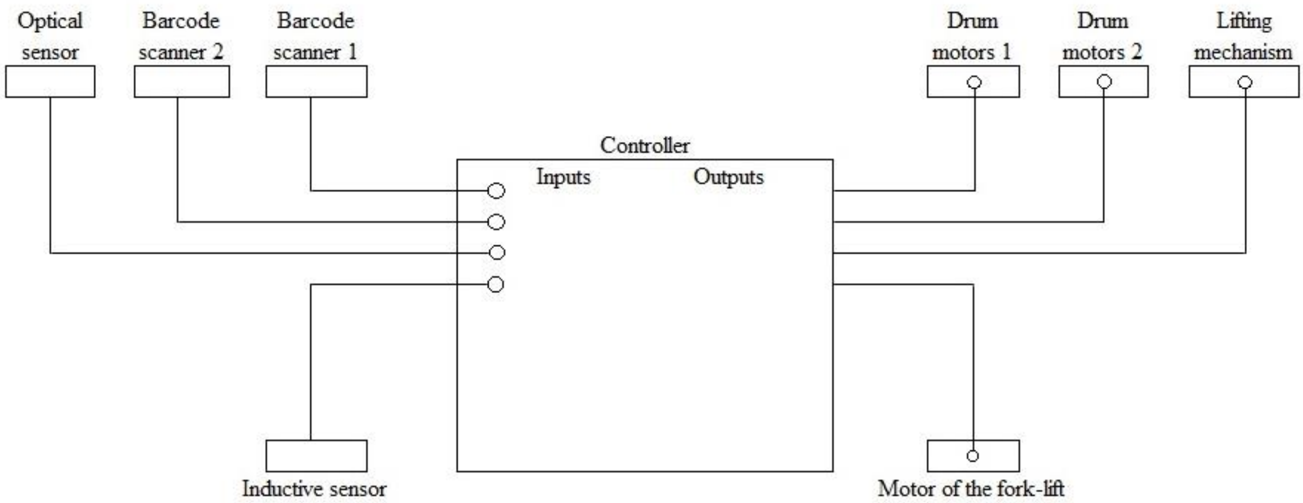

Fig. 3.19 Structural scheme of control of the robot

In order to assure a warranted control of the robot, a microcontroller is chosen. It is important to note, that the robot will have seven sensors: four optical sensors (two receivers and two transmitters), one inductive sensor and two barcode scanners. This information suggests that a microcontroller needs to have at least seven inputs and outputs. Nonetheless, the robot might be improved subsequently, so a safety factor must be taken into account. The microcontroller board chosen for the loading-unloading robot is UNO R3 ARDUINO (Fig. 3.20).

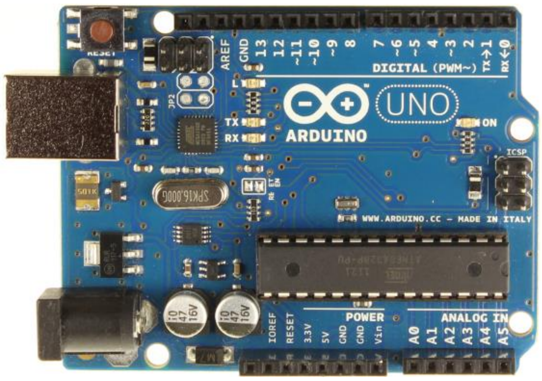

Fig. 3.20 Microcontroller UNO R3 ARDUINO [29]

This microcontroller has a USB and ICSP connections, power connection, fourteen digital inputs/outputs, six of which can be used as PWM outputs and six analog outputs [29]. Other important specifications are shown in Table 3.3; full specification sheet is given in Appendix 8.

Table 3.3 Specifications of UNO R3 ARDUINO microcontroller [29]

Processor	16 MHz
Operating voltage	5 V
Input voltage	7-12 V

3.3 Fire safety

One of the most important subjects that have to be taken into consideration is fire safety. The smart storehouse is designed to store oil, antifreeze and windscreen wash, all of which are naphtha based products and are, depending on the product, highly flammable. Most of the oils stored in the warehouse have a flashpoint higher than 200 ˚C, but fire safety measures have to be implemented for the safety of staff and the commodities. Nonetheless, fire regulations are created by the Lithuanian government and have to be fulfilled unquestionably.

The general fire safety instructions are presented in General Fire Safety Rules approved by the Sejm of Republic of Lithuania [30]. Several instructions are listed below:

- The primary fire extinguishing equipment must be present in buildings and facilities;
- Evacuation directions and informational signs indicating the location of the fire extinguisher or fire hose must be positioned so that at least one of each type of sign would be visible from any location in the room;
- Above the doors along the escape routes of hotels, hospitals and other facilities that can accommodate 50 or more people, luminous directional exit signs have to fastened 2-2.5 metres above ground.

- In case of fire, use of elevators, escalators and lifts for evacuation are prohibited, except where such facilities are designed for people to evacuate.
- In places where extremely flammable, highly flammable or flammable substances can occur (vapours of flammable gases, aerosols, dust) use no footwear or tools which could cause sparks to appear, also clothes which accumulate static charge [30].

These rules are created for general safety and have to be fulfilled in any type of premises irrespective of purpose of the area. Nevertheless, there are rules especially made for storehouses. These rules describe the manner in which the owner and storekeepers have to conduct the work:

- Commodities must be stored in groups according to the material which is used to extinguish the goods (water, foam, gas, etc.), as well as their physical and chemical properties.

According to the safety data sheets of the Mabanol oil, substances intended for fire extinguishing of the oil are foam, dry powder, carbon dioxide, sand, water spray jet and water mist. The only fire extinguishing technique, which should be avoided, is full water jet. Despite that, the oil in boxes and drums are separated and have their storing areas reviewed in Section 2.

- It is not allowed to keep electrical lifts, trucks and motor vehicles, and recharge their batteries in the warehouse. Handling mechanisms must be in working order. Autonomous mechanisms should be kept in storing areas when not operated.

The rules stated in latter paragraph are met when designing the layout of the warehouse. The loading-unloading robot is kept and charged at the area No. 1 (Fig. 2.4), which is designed entirely for that purpose.

- Materials not held on the shelves must be placed in stacks. In the warehouses with an area of more than 200 m^2, the materials not stored on the shelves, have to be stored in areas marked with stripes on the floor. It is prohibited to store materials not in the marked storage space [30].

The drums of 60 and 208 litres are held on Euro- and industrial pallets. Because these commodities are not stored on the shelves, the drum storing area No. 4 (Fig. 2.4) is going to be marked by a bright line as referred to in the Fire Safety Rules.

The first rule overviewed in this chapter states that fire extinguishing equipment must be present in all buildings. According to the Appendix 5 of the General Fire Safety Rules, a warehouse, which has an area bigger than 600 m^2 has to have two fire extinguishers of 20-25 kilograms or one forty-kilogram fire extinguisher. The computational measurement unit, starting from which, number of extinguishers have to be added, is 1200 m^2. The warehouse area is 1000 m^2, so oil storehouse must have two portable fire extinguishers of 20-25 kilograms [30].

The fire safety does not end in having an extinguisher. The fire safety sensors and a control panel must be installed in the warehouse.

3.3.1 Fire safety elements

Optical smoke alarms

Several fire alarms are created for detecting of fire. First type of fire alarms overviewed is optical smoke alarm. Optical smoke alarm is operating based on photo-electric principle using light scatter. A pulsed Infrared LED diffuses a light beam into the chamber of the sensor every ten seconds in order to examine if there are smoke particles in the chamber. The optical chamber fills with smoke when the fire starts entering through the opening vents (Fig. 3.21). In order to prevent false alarms from bugs entering the sensor, quality manufacturers protect the chamber with insect screens.

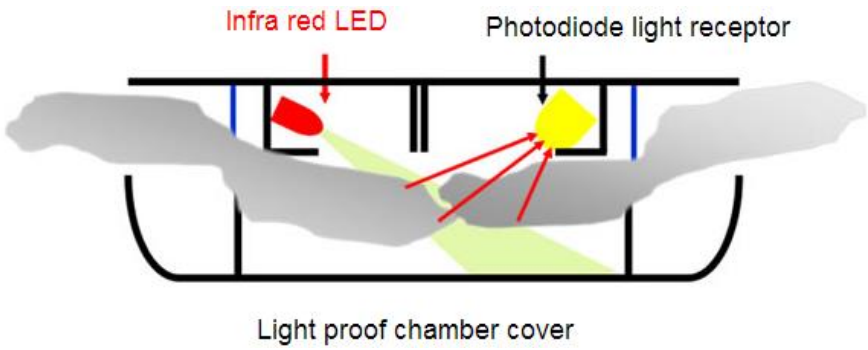

Fig. 3.21 Optical smoke alarm working principal [31]

When the smoke enters the sensor (optical chamber), the smoke corpuscles cause the IR light to scatter on the receptor, which reacts to photodiode light. When the light reaches the receptor, an integrated circuit receives a signal and activates a sound alarm, as well as the security company, which informs the firehouse about a fire. Best area suited for instalment of these types of alarms is premises where the fire spreads slowly, because the operational time of the sensor is delayed due to speed of smoke [31].

The optical smoke sensor, suitable for detecting smoke in the warehouse, is Vision 2020P manufactured by Honeywell (Fig. 3.22). The specifications are presented in Table 3.4 [32].

Fig. 3.22 Optical smoke sensor Vision 2020P [32]

Table 3.4 Specifications of optical smoke sensor Vision 2020P [32]

Operating voltage range	14 to 28 VDC (Nominal 24 VDC)
Application temperature range	-30 ˚C to +70 ˚C
Humidity	5 to 95% relative humidity
Max wire gauge for terminals	0.4 mm^2 to 2.0 mm^2
Height	32.5 mm
Diameter	102 mm
Standards	EN54 part 7
Approvals	LPCB Approved and CE Approved

Ionisation smoke alarms

The Safelincs describes ionisation smoke alarms:

"An ionisation smoke alarm works by ionising the air between two electrodes which are positively and negatively charged, this creates a small current inside the chamber."[7]

Similarly to optical smoke alarms, the ionisation chamber fills with smoke when the fire starts entering through the opening vents (Fig. 3.23). In order to prevent false alarms from bugs entering the sensor, quality manufacturers protect the chamber with insect screens.

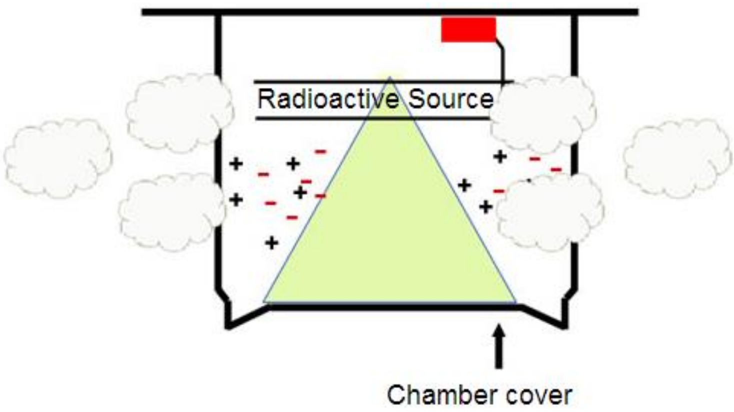

Fig. 3.23 Ionisation smoke alarm working principle [33]

When the smoke enters the sensor (ionisation chamber), the smoke particles cause the current in the chamber to change. When the current in the chamber changes, an integrated circuit receives a signal and activates a sound alarm, as well as the security company, which informs the firehouse about a fire. Best area suited for instalment of these types of alarms is premises where the fire spreads quickly, because the ionisation changes regarding the smallest appearance of smoke [33].

One of the suitable ionisation sensors for application in the oil storehouse is Discovery sensor 58000-500 (Fig. 3.24). The specifications are presented in Table 3.5.

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[7] How Ionisation Smoke Alarms Work by Safelincs. Internet access - http://www.safelincs.co.uk/smoke-alarm-types-ionisation-alarms-overview/

Fig. 3.24 Ionisation smoke sensor Discovery No. 58000-500 [34]

Table 3.5 Specifications of ionisation smoke sensor Kidde Firex KF1 [34]

Operating voltage	17-28 VDC
Supply wiring	Two-wire supply, polarity insensitive
Temperature range	-30 ˚C to 70 ˚C
Humidity	0 to 95% relative humidity
Approvals	EN54 Part 7:2002
Certificates	LPCB, VdS, BOSEC and VNIIPO Approved

Heat alarms

Optical and ionisation smoke alarms are created to detect smoke, while heat alarms, how the name suggests, are created to detect heat. A thermistor is included in the heat alarm design. This part of the alarm responds to all temperatures which are above 58 ˚C. The smoke alarms go of when smoke is detected, while heat alarms pick up the changes in temperature. When the fire starts, the temperature in the room rises. Hot air enters the sensor chamber and when temperature inside reaches 58 ˚C the integrated circuit receives a signal that fire has occurred activating an alarm and the security company, which informs the firehouse about a fire (Fig.3.25).

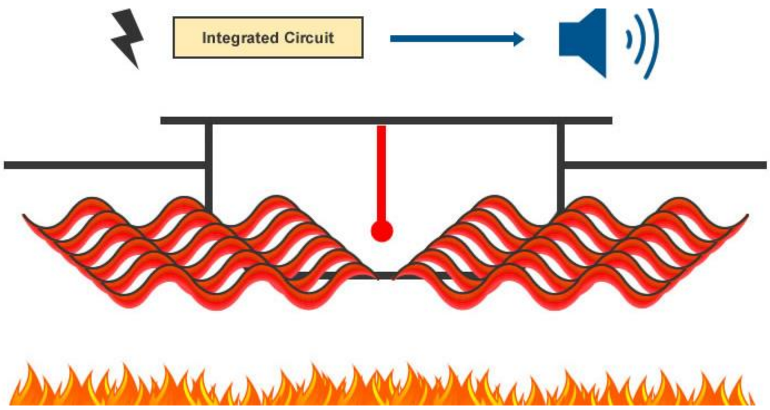

Fig. 3.25 Heat alarm working principle [35]

Heat alarms can be installed in the factories or plants, which carry out flame works or have inside transport, because heat alarms are not likely to react to smoke from welding or exhaust fumes

[35]. A heat sensor suitable for warehouse application is Honeywell sensor Vision 2020PT (Fig. 3.26). The specifications are presented in Table 3.6.

Fig. 3.26 Heat sensor Vision 2020PT [36]

Table 3.6 Specifications of heat sensor Vision 2020PT [36]

Operating voltage range	14 to 28 VDC (Nominal 24 VDC)
Application temperature range	-30 ˚C to +70 ˚C
Humidity	5 to 95% relative humidity
Max wire gauge for terminals	0.4 mm^2 to 2.0 mm^2
Standards	EN54 Part 7 and EN54 Part 5
Approvals	LPCB Approved and CE Approved

Considering the information listed above, conclusion can be made that the best fire alarm for oil storehouse is the Ionisation fire alarm. The choice was made taking into account that oil warehouse contains cartons of oil, antifreeze and windscreen cleaner. It is highly flammable and ionisation alarms are believed to be more suitable for fast fire detection. Nevertheless, the bottles of oil are packaged in boxes made of cardboard which emits a high amount of smoke when burning and is easily detected by the ionisation smoke sensors. Full specifications are given in Appendix 9.

Sounder

In case of fire, the sensors transmit a signal to the sound alarms which go off warning the staff of the warehouse that it is time to evacuate. A sounder, which is perfectly synchronised with the ionisation sensor Discovery No. 58000-500, is The Discovery Open Area Sounder Beacon (Fig. 3.27). Specifications of the sounder are presented in Table 3.7. Full specifications are given in Appendix 10.

Fig. 3.27 Discovery Open Area Sounder Beacon [34]

Table 3.7 Specifications of Discovery Open Area sounder Beacon [34]

Operating voltage	17-28 VDC
Protocol pulses	5-9 V
Maximum sound output at 90 ˚C	100 dB(A)
Operating temperature	-20 ˚C to +60 ˚C
Humidity	0 to 95%
Possible color	Red and white

3.3.2 Fire safety control

All the sensors and sounders have to be arranged in the warehouse according to the fire safety rules. The distance in which ionisation sensors must be placed from one another is 5 meters. This information is given in fire safety training for all the company managers and was taken into account when designing a sensor layout (Fig. 3.28).

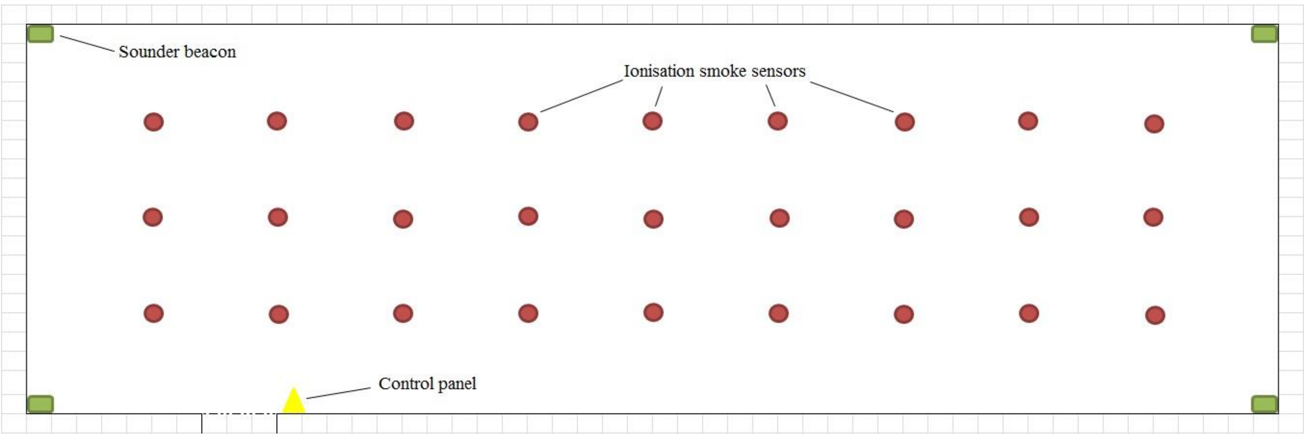

Fig. 3.28 Layout of fire safety elements

It is visible in Fig. 3.28 that there are twenty seven ionisation smoke sensors and four sounder beacons in the warehouse. A control panel is necessary to control these elements. Smoke sensors chosen for the warehouse are manufactured by Apollo Fire Detectors. Unfortunately, this company doesn't manufacture control panels. Nevertheless, Advanced Electronics Ltd is produce fire control panels, which support Apollo protocols. Fire control panel chosen for instalment in the storehouse is Axis 8 Loop Panel (Fig. 3.29). It is expandable from two to eight loops, can have up to 2000 fire zones. Specifications of the control panel are presented in Table 3.8 [37]. Full specifications are given in Appendix 11.

Table 3.8 Specifications of Axis 8 Loop Panel [37]

Devices per loop	Up to 240
Loop current	500 mA max per loop
Programmable Key Switch Inputs	16 V free digital inputs
Mains supply	200-240 V, 47-63 Hz AC
Battery capacity	2 x 24 V 4Ah
Size H x W x D mm	750 x 450 x 190

Fig. 3.29 Axis 8 Loop Fire Panel [38]

3.4 Burglary security

The last necessary step in smart storehouse design is burglary security. The warehouse contains high volume of various commodities, which is costly and has to be protected against possible attempts to steal. For this purpose, motion sensors and control panel must be used.

Motion sensor suitable for the warehouse is Honeywell DUAL TEC Motion Detector DT 8035 (Fig. 3.30). It is a small sensor with a wide detection range and optimum performance.

Fig. 3.30 Honeywell DUAL TEC Motion Detector DT 8035 [39]

The sensor is sleek in design and has a sealed construction. The optics and electronics of the sensor are assembled in the front of the sensor and protected with a cover. The cover protects the sensor from damage during installation and insects, which may appear in the premises. The specifications of the sensor are presented in Table 3.9. Full specifications are given in Appendix 12.

Table 3.9 Specifications of Motion sensor DT 8035 [40]

Coverage range	12.19 m x 17.07 m
Optics	Frensel Lens
Power	9.0 – 15 VDC
Maximum current	17 mA
Operating temperature	-10 ˚C to +55 ˚C

The control panel compatible with the motion sensors is OMNI848 by Honeywell (Fig. 3.31). This control panel is designed to collaborate with Honeywell motion sensors, has eight to forty eight security zones, which are obtained using zone doubling feature. The specifications of OMNI848 control panel are presented in Table 3.10 and full data sheet is given in Appendix 13.

Fig. 3.31 Control panel OMNI848 [41]

Table 3.10 Specifications of OMNI848 control panel [41]

Number of zones	8 to 48
Programmable relay outputs	Up to 20
Number of user codes	64
Tamper option by zone	Yes

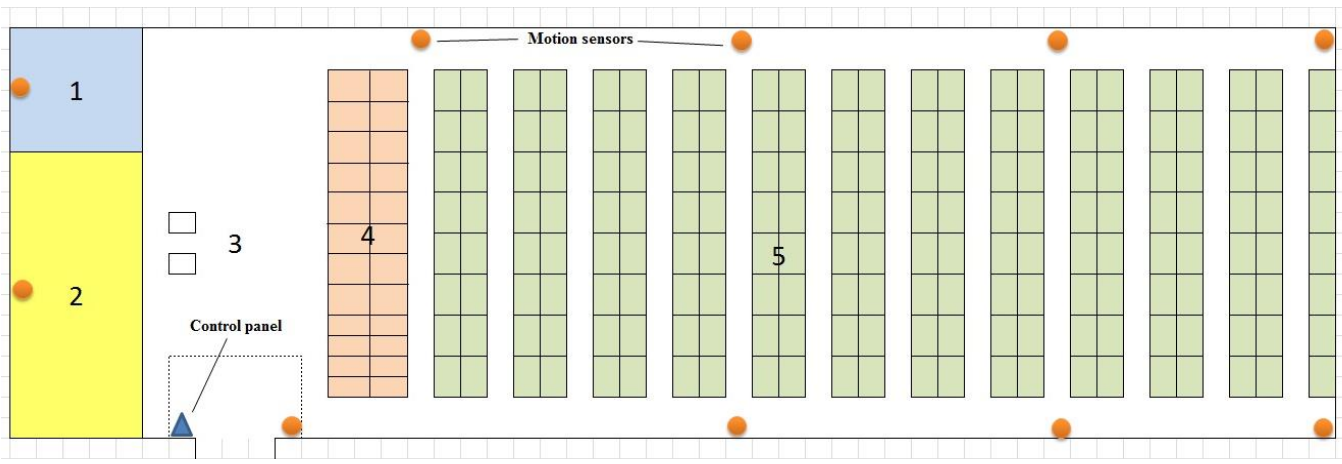

Fig. 3.32 Layout of the security elements

Fig. 3.32 shows the layout of all sensors in the warehouse and the position of the control panel. Sensors are spread out near enters of the storing area and by the entrance. The distance in between sensors is approximately 12 metres, which meets the coverage range of the motion sensors.

CONCLUSIONS

After fulfilling all the established goals which were set in order to implement the final Master's project the following conclusions are listed below.

1. The warehouse layout was presented and redesigned to fit the requirements of future loading-unloading robot.

2. The suitable racks for the warehouse were chosen – 225x200x100 cm Long-Span 600 rack.

3. The lift for the loading-unloading robot was chosen by comparing the two possible designs using SolidWorks Simulation and conducting buckling analysis. The Fork lift ATLET was chosen for the design with the buckling of 28.08 mm, when the buckling of the scissor lift was 53.2 mm.

4. Conveyor panel for the unloading of the cartons was designed using the Interroll 80i drum motors. The unloading time of the motors was calculated – 4.5 seconds.

5. Control algorithm for the loading-unloading robot was composed. The control elements of the robot were selected: Datalogic DS2400N-2K Series laser barcode scanner, Götting KG inductive guidance sensor and frequency generator, and Pepperl-Fuchs thru-beam optical sensor. The UNO R3 ARDUINO microcontroller was selected for the control of the robot.

6. Fire safety elements were chosen for the design of the storehouse: ionisation smoke sensor Discovery No. 58000-500, Discovery Open Area Sounder Beacon and the control panel Axis 8 Loop Fire Panel. Security elements were chosen: Honeywell DUAL TEC Motion Detector DT 8035 and Control panel OMNI848. The layout of installation for fire safety and burglary security elements was composed.

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APPENDIX

Appendix 1 – Specifications of ATLET Fork Lift

Appendix 2 – Dimensions of Conveyor Platform

Appendix 3 – Specifications of Interroll Drum Motor 80i

Appendix 4 – Specifications of Barcode Scanner DS2400N – 2K Series

Appendix 5 – Specifications of Guidance Sensor HG 19330

Appendix 6 – Specifications of Frequency Generator HG 57500

Appendix 7 – Specifications of ML30-P/25/102/115 Thru-beam Optical Sensor

Appendix 8 – Specifications of Microcontroller UNO R3 ARDUINO

Appendix 9 – Specifications of Ionisation Sensor Discovery No. 58000-500

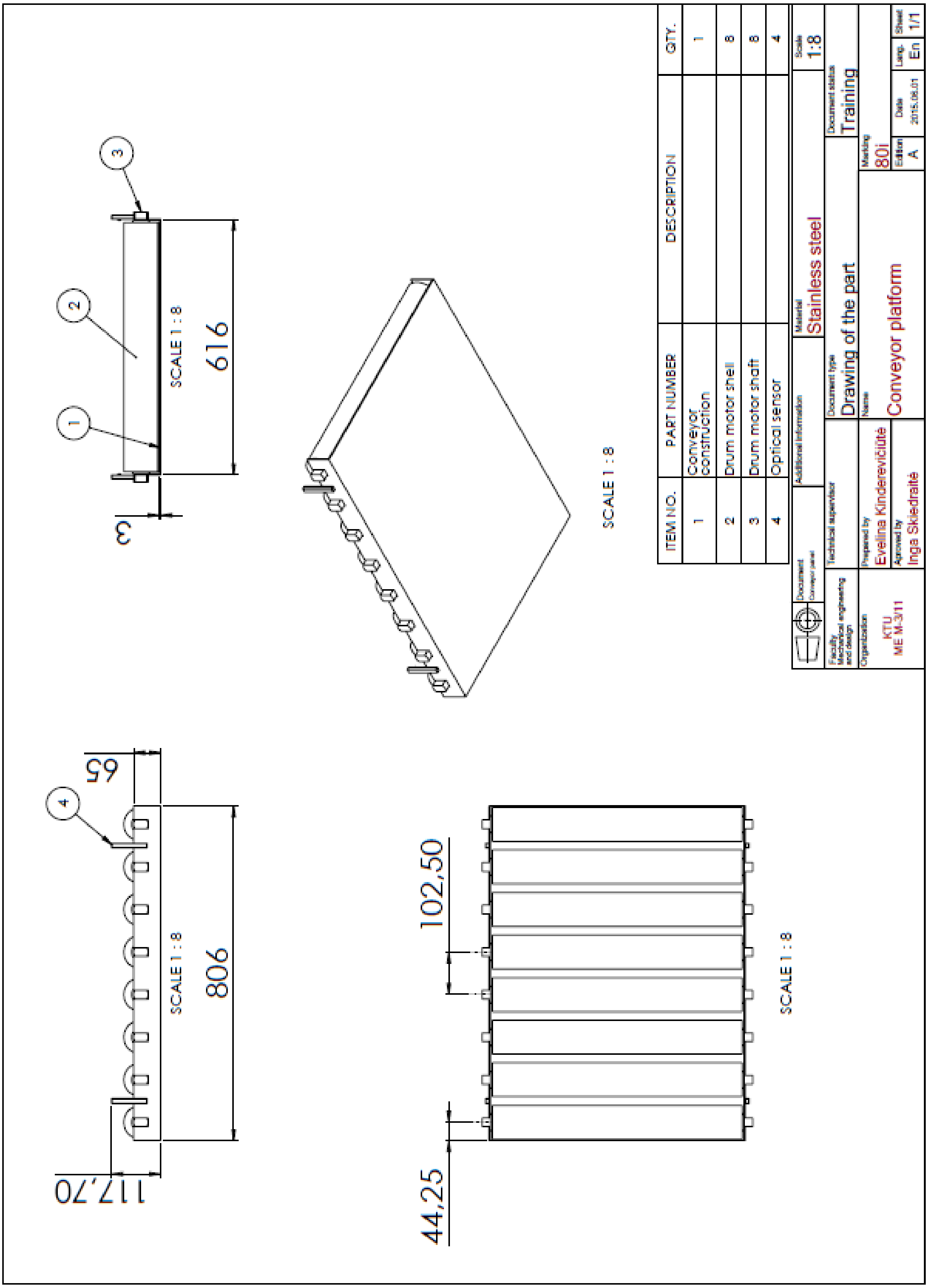
Appendix 10 – Specifications of Discovery Open Area Sounder Beacon

Appendix 11 – Specifications of Axis 8 Loop Fire Panel

Appendix 12 – Specifications of DUAL TEC Motion Detector DT 8035

Appendix 13 – Specifications of Control Panel OMNI848

Appendix 2



ITEM NO.
PART NUMBER
DESCRIPTION
QTY.
1
Conveyor construction
1
2
Drum motor shell
8
3
Drum motor shaft
8
4
Optical sensor
4
SCALE 1 : 8
616
3
806
65
117,70
102,50
44,25
Material
Stainless steel
Scale
1:8
Document type
Drawing of the part
Document status
Training
Name
Conveyor platform
Marking
80i
Prepared by
Evelina Kinderevičiūtė
Approved by
Inga Skiedraitė
Organization
KTU
ME M-3/11
Edition
A
Date
2015.06.01
Lang.
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