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DEPARTMENT OF AUTOMATION AND
INFORMATION

AUTOMATED WAREHOUSE
BACHELOR'S
THESIS

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BACHELOR'S THESIS ASSIGNMENT

I. Personal and study details

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Faculty / Institute: **Faculty of Mechanical Engineering**

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Study program: **Bachelor of Mechanical Engineering**

Branch of study: **Information and Automation Technology**

II. Bachelor's thesis details

Bachelor's thesis title in English:

Automated warehouse

Bachelor's thesis title in Czech:

Automatický sklad

Guidelines:

Design an automatic transport system in the clothing warehouse. System will be able to store the products and to prepare orders.
1) Make research about hte existing solutions.
2) Design your own overall solution. Focus the control system, logistics, efficiency, cost.
3) Create general 3D virtual model of your solution.
4) In more detail solve technological particles of the system:
a) Forcing mechanism of hangers movement.
b) Construction of a switch to the parking track.
c) Hook to catch/release the hanger on the rail.

Bibliography / sources:

S. Pell, A. Willig and G. Woodward, 'Evaluating V2X Technologies for Warehouse Intelligent Transportation Systems,' 2021 IEEE Vehicular Networking Conference (VNC), 2021, pp. 95-102, doi: 10.1109/VNC52810.2021.9644675.
Z. Weiwei and C. Ying, 'Intelligent Technology Related to Warehousing and Distribution in Intelligent Logistics,' 2020 International Conference on Wireless Communications and Smart Grid (ICWCSG), 2020, pp. 175-177, doi: 10.1109/ICWCSG50807.2020.00046.

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Date of bachelor's thesis assignment: **29.04.2022** Deadline for bachelor thesis submission: **09.06.2022**

Assignment valid until: _____

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III. Assignment receipt

The student acknowledges that the bachelor's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor's thesis, the author must state the names of consultants and include a list of references.

6.05.2022 Date of assignment receipt	Student's signature

I declare that I have worked out this thesis independently assuming that the results of the thesis can also be used at the discretion of the supervisor of the thesis as its co-author. I also agree with the potential publication of the results of the thesis or of its substantial part, provided I will be listed as the co-author.

Prague, ……

……
Signature

Title: Automated Warehouse

Author: Berkehan Merden

Supervisor: Ing. Pavel Trnka, Ph.D.

Abstract:

The aim of this thesis is to design automated warehouse specifically hanging products. Importance of this thesis is to bring a solution for middle-sized companies which are having a problem with storing and sorting products until the packaging. Automated warehouses will be a key factor for the companies which are competing by lowering prices especially for online businesses therefore those companies have to decrease their workforce and increase their efficiency by automatize their logistics. Research during the preparation is done by investigating existing companies which are working on automizing their customers logistic processes. The solutions are explained in 3D models with their descriptions and their advantages and disadvantages for forcing mechanism, switching between line to line and catch and release movements. General 3D view of automated warehouse and explanations of the processes with its details and missing parts. This thesis shows that there are variety of solutions for automation for logistics and it is possible to solve middle-sized companies logistic needs with an affordable investment.

Keywords: Aluminium line, sliding channel, automated warehouse, product entry, pushing mechanism, switching between lines

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1. Introduction

Any modern warehouse would need an automated systems to increase the efficiency of preparations of the selling goods. By transferring the existing business warehouse to an automated warehouse would decrease the need in work force, heating and would increase the efficiency of the preparation of the selling goods and accuracy of the orders. An automation warehouse would decrease the time spend per order therefore with less warehouse space area it is possible to prepare more accurate orders which should increase the company operation, sales and service quality to customers and create opportunity for the companies to focus on more to sales and marketing instead of logistic operations and it is problems.

The aim of this thesis is to make research about the existing solutions of the automated warehouse for textile products and design a realistic solution according to needs of a textile warehouse.

1.1 Definition Of Warehouse Automation

Warehouse automation is becoming more common as businesses and warehouse managers try to boost productivity, cut costs, and improve productivity. However, people's perceptions of what warehouse automation is are highly varied. Automation in the warehouse includes anything from robots to automated procedures, and it promises to significantly increase efficiency and effectiveness.

1.2Types Of Warehouse Automation

Under the general heading of "warehouse automation," several technologies that support human employees or complete activities from beginning to end are included. To maintain inventory and distribute items, warehouses manage a range of duties and processes.

The technologies used in warehouse automation solutions, which comprise a variety of approaches to accelerating warehouse operations, are as diverse.

Goods-to-person technologies:

Goods-to-person (GTP) usually includes robots or some other technologies that bring goods to employees for picking and packing the products. GTP usually includes an automated warehouse and conveyor systems.

- Automated storage and retrieval system:

It is also called AS and RS are the technologies using vehicles, cranes and carousels in order to move the goods inside the warehouse and also store the items in warehouse stock locations.

- Conveyor systems:

Conveyor systems are one of the oldest warehouse automation systems. Conveyors move the goods inside the warehouse in the assembly channels to move the goods to employee working areas which are picking and packing also shipping areas.[1]

Pick-to-light systems:

Pick to light systems are simple method to increase the picking speed and precision thus increases the efficiency while decreasing the cost of the investment compared to other methods and the operation costs per goods.
Pick to light system consists of several bulbs and push buttons with no paper in the employee hand, System shows the next good to be picked up by lighting the bulb and showing how many pieces operator must take and then operator pushes the button and put the goods to collection box or unit and moves on next good to pick up by again bulb light.(3)

Figure 1: Pick-to light systems. [2]

Voice picking and voice tasking:

Voice tasking solves goods pick by communication of pickers and taskers.
It is possible to assemble this system with wireless headsets to coordinate and give the tasks. [1]

Sortation system:

Sortation system sends goods to correct locations using different technologies and separate items, sending them to specific locations or picking points or packing stations.

Collaborative mobile robots

Collaborative mobile robots with employees to increase the picking accuracy and efficiency, helping employees to through picking process.

Drones

Drones are technically robotic machines and they are not designed as advanced computers but they are used for inventory management, barcode scanners are added to their structure. These drones are counting the stocks of the warehouse and give information to staff about left stocks that can be used while restocking or item location. It can also help staffs to identify wrong location of products. Drone is being used for deliveries and companies are trying to improve their service by using drones for shipping the goods. [1]

1.3 Advantages and Disadvantages of Automated Warehouse

Automated storage and retrieval system (ASRS) one of the most productive investments one can make in a warehouse or factory operation. By installing an ASRS in place of a conventional forklift-based storage and product handling operation, companies may improve productivity, accuracy, and safety while reducing product damage and human error.

The integration of an ASRS into a highly customised business, however, might not be advantageous. Given the relatively high initial expenses, businesses intending to invest in this technology must perform a comprehensive financial analysis.

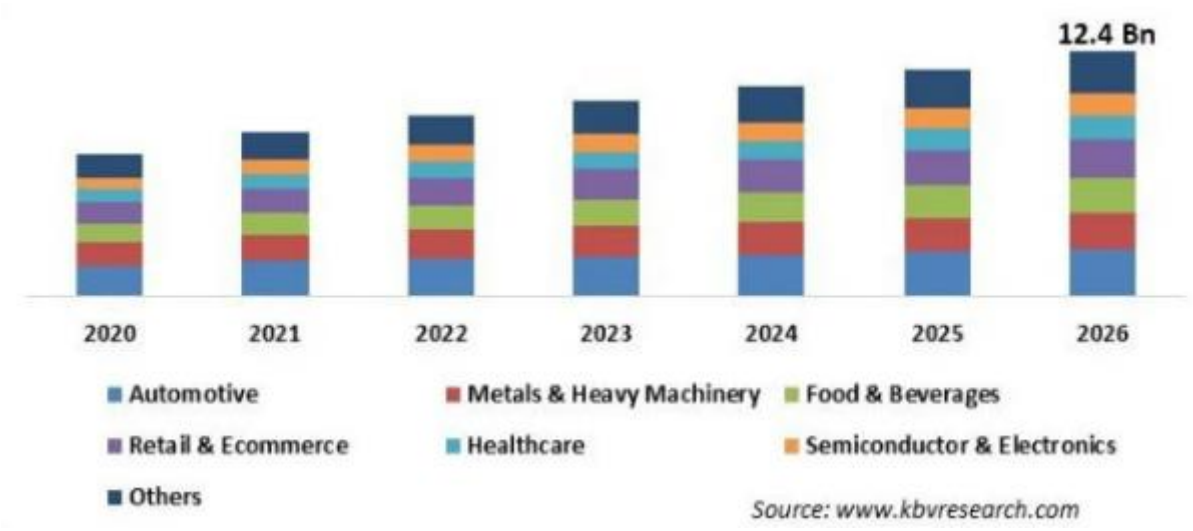

Figure 2: ASRS market size projections by end-user.

According to the studies visible above Figure 2, Automotive sector is the largest sector for ASRS solutions. Every year it is expected to continue this trend to increase.

Advantages of ASRS	Disadvantages of ASRS
High-Density Storage	Initial Investment
Better Safety Of Operations	Inflexible Tasks
Increased Accuracy and Efficiency	High Electric Cost
Less Human Error	
More Prepared Orders Per Unit Time Compared to Not Automated Warehouse	
Less Heating and Light consumption	

Table 1: Advantages and disadvantages of ASRS.[5]

Advantages:

High-Density Storage
ASRSs are the most effective systems to increase warehouse capacity. Since it is possible to design the stocking structure vertically it allows to store more products. [5]

Better Safety Operations
Load balancing on the forklift is one of the most dangerous jobs, assembly of effective ASRS can eliminate all risks connected with human interaction with the lifted goods. During maintenance ASRS must be locked according to it is safety procedures to eliminate risks during maintenance. [5]

Increased Accuracy and Efficiency
As other automated system, ASRSs are designed to complete repeating tasks with high precision. It reduces labour costs, less product waste is some cost saving factors.
Other important part is increased accuracy of product operations data. All ASRS are controlled with warehouse management systems those data is automatically transfer between internal systems and identifies product information such as quantity of products and location. [5]

Less Human Error
Thanks to Management system are done by computer human error should be decreased significantly with operating technologies at the warehouse. Less human error means less returns from customers and increases the customer satisfaction that we can consider as very important advantage when it comes to customer service.

Less Heating and Light consumption

Automated warehouses are able run without heating the warehouse environment for the fully automated areas. Companies can separate the picking and packing areas from fully automated areas and operate those areas with different temperatures so that companies can save significant amount of energy while they are satisfying employees.

More Prepared Orders Per Unit Time Compared to Not Automated Warehouse

Automated warehouses can prepare more orders per unit time with compared to traditional warehouses thanks to its advance technology.

Disadvantages:

Initial Investment

Designing and building ASRS is a large and complicated construction project. Because of the structure which withstands loads to be stored, construction cost is too expensive that a lot of companies are not able to reach this investment that could benefit their business improvements. [5]

Inflexible Tasks

Most ASRSs are designed for perform a single type of task so design must be planned according to the various needs so that in future it will not be able to change because of current design or the cost of new design. So, it is important to decide the future volume and product lines. [5]

High Electric Cost

When it comes to electric consumption that is normal that automated warehouse will consume more electricity than the traditional warehouse but the total energy per piece of the goods delivered energy should be decreased in the end however companies should design their warehouses with possible renewable electricity energy sources for sustainability and cost management.

2. Research For Existing Solutions for Automated Warehouse

There are many solutions for automated warehouse for automobile industry but there are few companies which are helping their customers to automatically manage their warehouse for textile products. The reason for that is textile products don't have solid volume and shape, so solutions are usually more expensive or more complicated. One other reason is that also there are few mega companies that can invest that much source to automatic solutions.

One of the most important company is PSB gmbh.

2.1 Company PSB gmbh.

PSB gmbh was founded by Franz Klein in Pirmasens in 1887. It is one of the leading companies in the intralogistics in Europe. PSB is calling their self as medium sized company but reality is different because even their smallest project costs millions of Euros.[6]

Companies important claim is that they are supplying complete system from a single supplier. According to PSB, other companies are outsourcing solutions from different providers and producers and then they are only organizing the general solution without producing material and solution. However, that claim can be correct because solving all the parts of the system is significantly difficult for financial reasons. Not only financial reasons but also engineering is also important. Company should have try smaller projects with all parts and then improve 1 compact solution in the end and to that they should have been enough experience from actually working systems.[6]

PSB claims that design, production, assembly, IT, commissioning, maintenance and customer service all these objectives are done by single supplier which actually is very important. It could decrease the time spent on project without communicating other companies. Responsible is made by a single provider so that they can plan anything they want and they can solve all the problems by their own which is very effective. [6]

2.1.1 Storing

PSB has many solutions for storing the products. Interest of this thesis is hanging goods, which is mostly textile good.

Figure 3: Storing hanging products.[7]

They are hanging similar products together and when product is needed system is carrying them to moving line. By this solution product storage density is increased.[7]

2.1.2 Picking

PSB pouch sorter is effective solution non shaped products. It can be used for many different products to carry, storage and for sorting. It can be thought like it is a shopping bag as thinner and more quantities.[8]

Figure 4: Pouch sorter.[9]

2.1.2 Sorting

On the sorting side company used special solution which is not easy to understand. But simply it can be explained that products are moving trough line are coming to sorting point then with their special technology products which are sold or needed to be packed are sorted to another line, products which are sorted getting closed to packing area by the help of gravity, there is no pushing for only gravity is solving this problem.

Figure 5: micro-trolley sorter.[10]

2.2 Designing Own Overall Solution

Designing own overall solution can be understandable by 2 parts. One part can be understandable as 2D or 3D design an logical explanation of overall design and second part can be expressed with finding solutions on the market. 2D and 3D design is explained in chapter 3. Chapter 2.2 will be focused on control system, logistics, efficiency and cost of the project to have some idea.

2.2.1 Control System

Automated control systems are important for the projects. On those systems Programmable Logic Controllers (also called as PLC) are used. But not all PLCs can be used on every project. Choosing the right PLC brand is not a simple decision, that decision can affect all the project by efficiency or speed.[11]

The importance of using PLC on automated projects can be described with some features and advantages.

- Efficiency: Modern PLCs have high memory capacity and those PLCs are covering less space.
- Flexibility: A single PLC can operate multiple mechanisms at the same time.
- Cost efficiency: Even lower range of PLCs can control machines.
- Safety: PLCs can decrease the risk on project area.

Those advantages are important for the overall system so that project can be controlled by those PLCs safely and for long periods.[12]

2.2.1.2 How to Choose the Right PLC

The architecture of a PLC consists of Input/Output(I/O). The input section is connecting with sensors, control panels, switches and with other input sources. The output section can be connected with a lamp, motor, solenoid or any other output device that can be controlled by input signals.[13]

The basic function of a PLC consists of CPU, Inputs and Outputs. The information taken as form of inputs it is performed as logic in CPU, then that information is transferred to outputs as “on” or “off” according to the logic.[13]

- Power Supply, PLC can support 24V DC, 24V AC or 230V AC. It is good to choose PLC according to the transformer used to power supply the control panel. And this PLC should send enough voltage (output) to controlled device that can receive necessary input.[13]
- Number of Inputs and Outputs are important that should be enough for selected area it will be enough.[13]
- Communication Protocol must be considered while choosing the PLC, the devices should be able to use the same communication protocol.[13]
- Environment affects is important, according working temperature of the system, suitable PLC should be choosing for the necessary work.[13]
- High-speed devices require high-speed inputs and outputs. It is also necessary to check the CPU speed as scan time if it is enough for the demanding work. [13]
- Some applications demand specific programming languages and specific libraries.[13]
- Operator interface is important for operator in case operator requires graphical interface it is necessary to choose the correct PLC which can support the demand. [13]

Choosing Siemens S7-1200 PM1207 could be good solution to control the mechanisms. Price is good to use for several PLC for each section so that when there is a error on the PLC other mechanisms can continue working without affecting rest of the automated warehouse. Siemens has good customer service through the Czech Republic.

POWER SUPPLY S7-1200 PM1207
SIMATIC S7-1200 POWER MODULE PM1207 STABILIZED
POWER SUPPLY INPUT: 120/230 V AC OUTPUT: 24 V DC/2.5 A

Figure 6: Siemens S7-1200 PM1207 PLC. [14]

Features of the PLC can be found in figure 7.

Input	
Input	1-phase AC
Supply voltage	
• 1 at AC Rated value	120 V
• 2 at AC Rated value	230 V
• Note	Automatic range selection
Input voltage	
• 1 at AC	85 ... 132 V
• 2 at AC	176 ... 264 V
Wide-range input	No
Overvoltage resistance	2.3 × Vin rated, 1.3 ms
Mains buffering at Iout rated, min.	20 ms; at Vin = 93/187 V
Rated line frequency	50 ... 60 Hz
Rated line range	47 ... 63 Hz
Input current	
• at rated input voltage 120 V	1.2 A
• at rated input voltage 230 V	0.67 A
Switch-on current limiting (+25 °C), max.	13 A
Duration of inrush current limiting at 25 °C	

Figure 7: Siemens S7-1200 PM1207 PLC datasheet.[14]

The price of the Siemens S7-1200 PM1207 is around 100 Eur. Automated warehouses will use more PLCs so it is possible to get better price on higher quantities.[15]

2.2.2 Logistics

Most of the logistic part is done by aluminium lines. Supply of those lines or it can be called on the market as channel, is necessary to solve on the beginning of the project. Every other step is depending on those lines. Design of the carrying hanger, forcing hanger, the design mechanism of switch between different lines. There are more solutions on the market for carrying the articles.

Figure 8: T-slot Aluminium 100 mm. [16]

T-slot Aluminium profiles or channels can be used on the project (see figure 8). This solution is the closest material what was designed on the project. The price of the material for 1200mm is 14 USD but this is too expensive by per piece price [16].

Czech Republic market prices are around 10 Euro per meter (profile dimensions are 30x30 mm). According to the seller weight of the material per meter is 0.85 kg. The usual production dimension on standard production for those kinds of profiles are 6040 mm. [17]

But in order to make some comparison it will be useful to make some calculation:

Current price of the Aluminium price per kg is 2.40 USD (25.7.2022) [18].

By simple calculation cost of the profile per meter could be minimum 2.4 Euro -10 Eur. At the easily accessible market price is 10 Euro which is the highest price can be supplied, 2.4 Euro is the cost of the material. Then there should be strong bargaining with the producer to get better price for profile. Of course, they can't sell it to 2.4 Euro, because it is their material buying price. If the producer company adds 100% margin to their buying price for their production expenses, most logical price should be from 5 Euro – 10 Euro range. For logistic cost reason it is important to find producer on the country where project is designed.

2.2.3 Cost Approximation Approach

The cost calculation of the overall project can be done approximately. First, materials and devices can be listed to understand the needs of the project:

Materials:

- Aluminium profile
- Moving particles
- Carrying hanger
- Moving hanger
- Steel cable
- Pulley
- Other mechanical needs

Devices:

- PLC
- Electrical and data cable
- Proximity Sensor
- QR code reader sensor
- Touch sensor
- Computer
- Pneumatic piston
- Air compressor
- Electrical motor

Software:

- PLC software
- Operating software

Engineering:
Engineering of the project can be estimated with the help of Work Breakdown Structure (WBS). With WBS, the project can be divided into distinct work components and organized hierarchically. The product, or items, that must be created and manufactured. It connects the many tasks that must be completed with one another and with the result. In other words, the WBS is a methodical way to segment a product into smaller. It is utilized for execution, control, cost assessment, and planning.[19]

Technical Assembly of all the system and testing:

Assembly of devices and materials must be done by professional technical stuff and all the devices and materials should be according to project, all the parts should be assembled by it's professional.

3.Creating General 3D Model of Automated Warehouse

3.1 Information of the Software Used on 3D Modelling

Automated Warehouse was designed for middle-sized company which would store 300.000-500.000 pieces of products needed to be hanging by hanger. Design is made by Autodesk AutoCAD 2019 but updated by 2023 version.

3.2 Background of the Designing Process

The Reason why it is needed to design automated warehouse is that initial investment is too much for companies therefore there is no middle-sized company solution in the market.
The reason why there is no solution for the middle-sized company is that engineering expenses is high for designing and planning for each company different solution. The expense of the materials used the cost of the electronical devices, cost of the software is expensive so that companies are not able to invest on these necessary systems which is understandable. But there should be a way to help those companies which doesn't want to invest 10s of millions of Euros to those systems. The way to make it happen could be to repeat the same solutions for more companies which would decrease the cost of engineering, the time is spent on the planning and engineering processes.

The total cost of the engineering, materials, planning, logistic, software and hardware is not the only cost but also finding suitable warehouse renting it during the assembly and testing part is a cost for the investor.

On this General design focus is on the basic ideas of receiving products, transferring them to blue lines to move the products to packing point B and transferring products which will be sold in time to red stocking lines. It is simple and least complex idea to solve the logistic of selling products to decrease the cost of employment, increase the picking and packing speed and decrease the error of sending wrong product to customer also decrease the mistake of wrong stocks which is one of the biggest problems of logistics but it is not visible for companies. Wrong stocks create much bigger problem that customer orders are delayed or cancelled so customer satisfaction is decreasing that way companies are not able to catch the real potential of their products.

This system is not only designed for only 1 company, but also logistic companies can use it too for many b2c customers that they can send to automated warehouse and they will take care of logistics of their sales and products so that they can focus on their marketing, restocking and adding new products on their catalogue.

3.3 Top View of the Automated Warehouse

The design is made up for 40 meters by 50 meters which gives us 2000 m^2 in total. In order to be able to make 2 floors of products hight of the warehouse is around 6 meter so it gives us 12000 m^3 . Figure 9 is the top view of the automated warehouse for simple imagination.

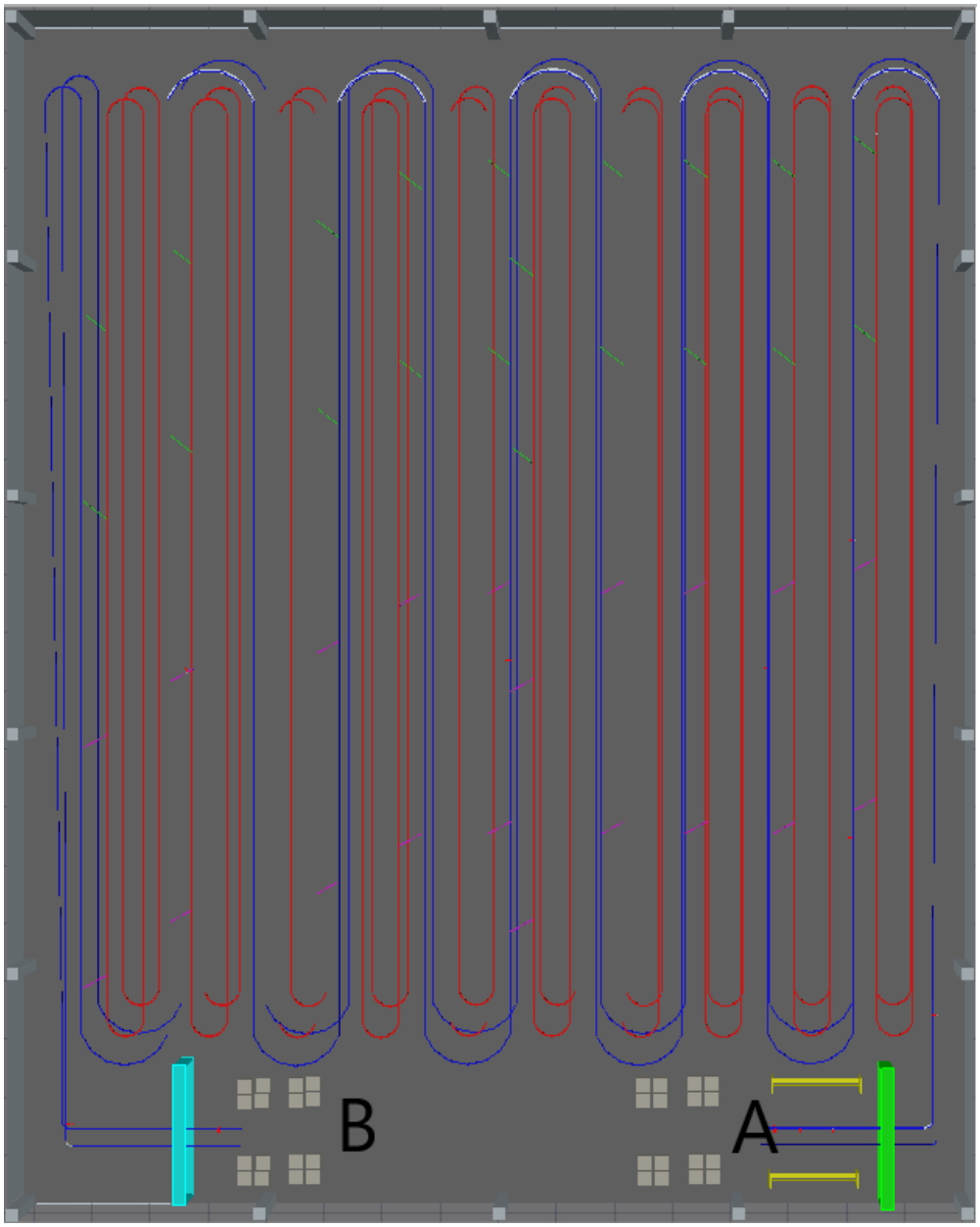

Figure 9 : Automated warehouse Design Top View.

3.4 Explanation of Important Areas

The design consists of 4 important areas in general in order to simplify the explanation of the design.

- Product entry area (Part A).
- Picking and packing area (Part B).
- Product transfer or product moving area (Blue Line).
- Product Storing area (Red line).

Product entry area (A):

This area is for accepting the new coming products from producer or b2b sellers. This part will happen semi-automatic since taking out products from boxes is complex process for automation employee or human interaction is needed. Employee is supposed to take out the products from boxes and put them to wider hanger for easy organization.
After that products are necessary to be scanned and connected to single unique hangers that will be hanged until the end of their lifetime at the warehouse which is packing area after they are sold.
Product entry area is also important to count the receiving products in order to confirm the seller quantities. Seller quantities are usually entered to warehouse database in advance products will be delivered to product entry area. Confirmation of new goods with right quantity is extremely important because when a product is sold warehouse should be able to send it to customer and if quantity is less than it was entered to database there will be an error on the order that products is missing. This case is the case that automated warehouse or any other traditional warehouse is trying to avoid.

Picking and packing area (B):

Picking and packing area will be connected with blue line like figure 9, this area is for preparing the orders for selected products and products which are moving through the blue line. At the figure 9 there could have been more details; products which are moving through blue line they will reach at the and picking and packing area there should have been more packing points the reason for that is that there will more orders so more employees should be packing at the same time and products are supposed to come to different employees from different channels.
So, it is important to have more picking and packing points to be able to pack more orders a unit time.

Product transfer or product moving area (Blue line):

The blue line is the line that products are moving in order to reach the correct location. For a product which has entered to product entry area the journey is starting. Single hanger for each product is assigned and then this hanger is moving through the blue line with it is assigned hanger.
Now this product can go to red line for storing, the algorithm will decide if product should be stored on the right side of the warehouse or left side of the warehouse according to the figure 9. The algorithm should decide if product is sold more than x amount, store it in the right side, if not, store it on the right side. Reason behind this logic should be preparing the ordered good faster.

The pink thin lines are designed to transfer products from blue lines to red lines (storing lines) and green thin lines are for transferring products from red lines(storing lines) to blue lines, after a product transferred to blue line then it needs to move to picking and packing area and picked and packed for the order.

There is a missing part on the design about blue line, after products are delivered to pick and pack area the pusher hanger and carrying hangers are supposed to turn back to product entry area in order to carry and push new products so that it should be closed chain, but design at figure 9 is missing this part.

Product storing area (Red line):

The red line is designed for storing the products. After products will pass the product entry area(A) they will move forward to blue line. Blue line will carry them to red lines and thin green lines they will transfer to red lines and until they are sold, they will stay in the red lines.
System should be deciding when a product starts selling more than x quantity per unit time they should be transferred to more left side of the warehouse according to figure 9.
The red lines are supposed to be turning all the time by constant speed ideally the most efficient speed of the turning motors. According to the sales of the business system could increase the speed of the redlines in order to increase the shift between redlines and blue lines so that more orders can be prepared per unit time and more new products can be entered to warehouse since more products will leave the system.

3.5 Front View of the Automated Warehouse

The automated warehouse on the figure 10 is the front view of the warehouse. This warehouse is designed for 2 floors of stocking and moving lines. From figure 10 it is easier to understand the lines. Two floors are not connected to each other in order to increase the speed of the preparation. But it is possible to connect 2 floors in the picking and packing area the reason could be that 2 3 different product can be at different floors, but they have to be send at the same time so for easy organization of the employee it would be good to connect two floors at the picking and packing area.
If this process is made automatically the speed of the orders should increase and human error should be decrease.

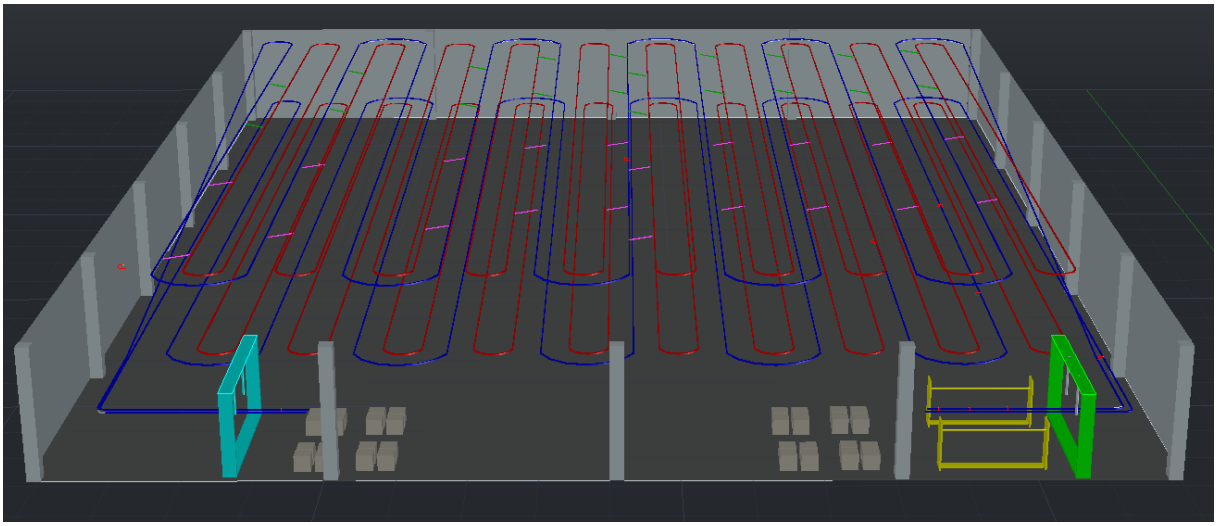

Figure 10: Front view of the automated warehouse.

The idea of connecting 2 ends of the blue lines, can be understandable from front view better. After products reach to picking and packing area, the hangers should be freed by an employee for the reason to pack them for orders. Free hangers and free pusher should return to product entry area in order to collect new products.

3.6 UML Diagram of Lifecycle of a Product

The UML diagram is created for simply explain the lifecycle of the product from entering to product entry area until the picking and packing including processes on redlines and blue lines.

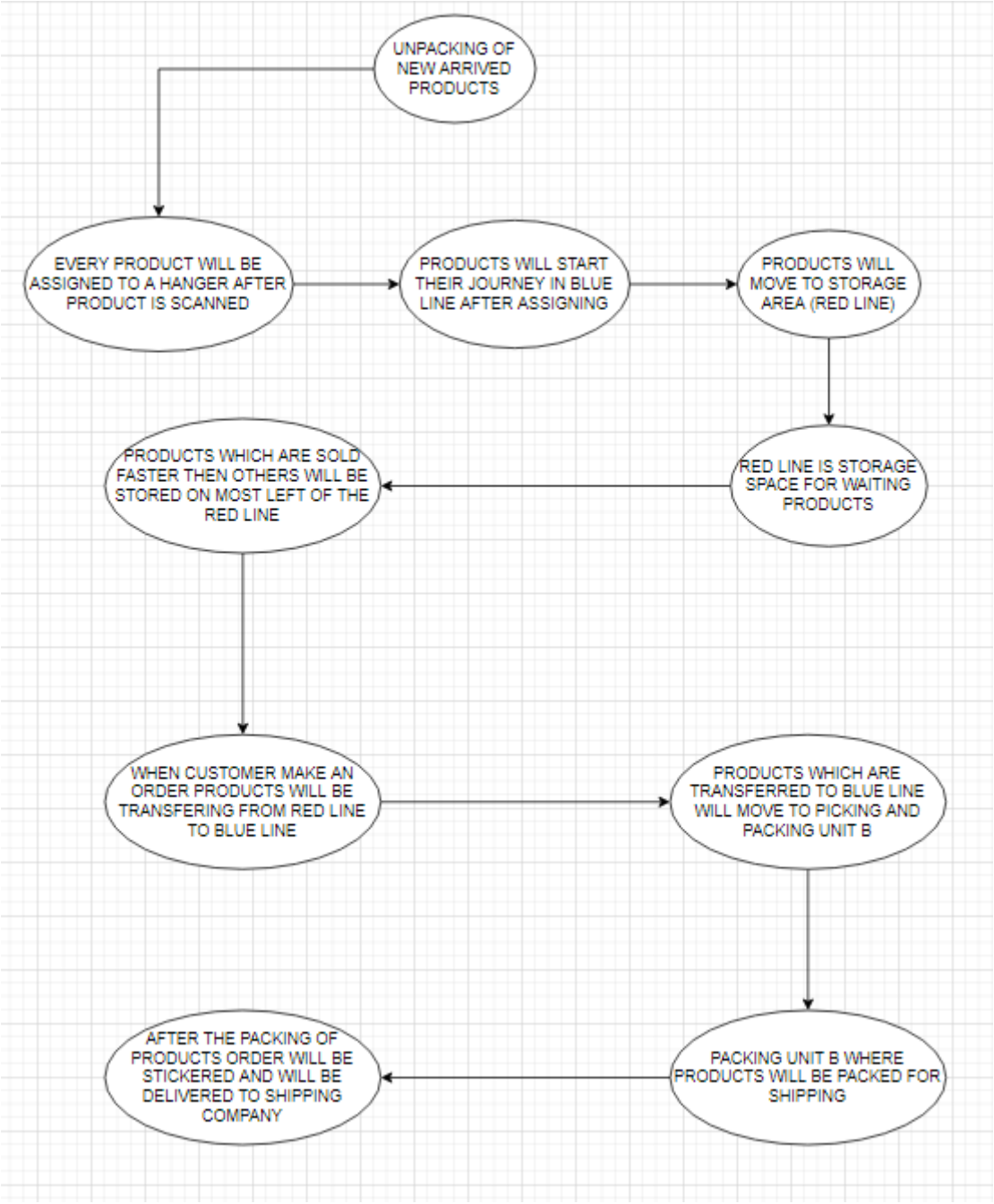

Figure 11: Simple UML diagram of Automated Warehouse working processes.

4 Solving Technological Particles of the System

4.1 Introduction

Automated warehouse thesis chapter 4 is focused on solving technological particles of the automated warehouse. There are 3 parts:

- Forcing mechanism of hanger movement
- Construction of a switch between lines
- Hook to catch and release the hanger

First of all, it is important to decide how the line or the rail structure should be designed but it is not easy to properly decide because there are many solutions to carry and move the carrying hanger and forcing hanger. With different structures there are different advantages and disadvantages at different processes. The difficulties are not only at the processes but also on the project structure of these moving parts and the line or channel as a cost. If a warehouse will have 500.000 carrying hangers than there should be 500.000 forcing hangers which makes total of 1000000 moving products.

4.2 Program Used on Design for Below Focuses

Forcing mechanism of hanger movement, construction of a switch between lines and hook to catch and release the hanger has been designed on Sharpr3D on an iPad. This application is very similar to AutoCAD programs, but it is easier to create and design projects. Some processes which are hard to apply on AutoCAD programs are simplified on Sharpr3D. It is also good to be able to use pen for iPad that can allow design some objects easier. It is also easy to transfer from 2D to 3D design.

The discussion will explain the advantages and disadvantages of different designs and their process problems of the line designs. The decision is affecting all other solutions of problems.

4.2.1 First Design of Line Structure (single recess)

First Design of line structure is visible below at figure 12, in this design plan was to have only 1 line and create moving force under the moving particle, but there was problem at the turning and it was difficult to create a forcing mechanism under moving mechanism because there will be only small gap to use this space.

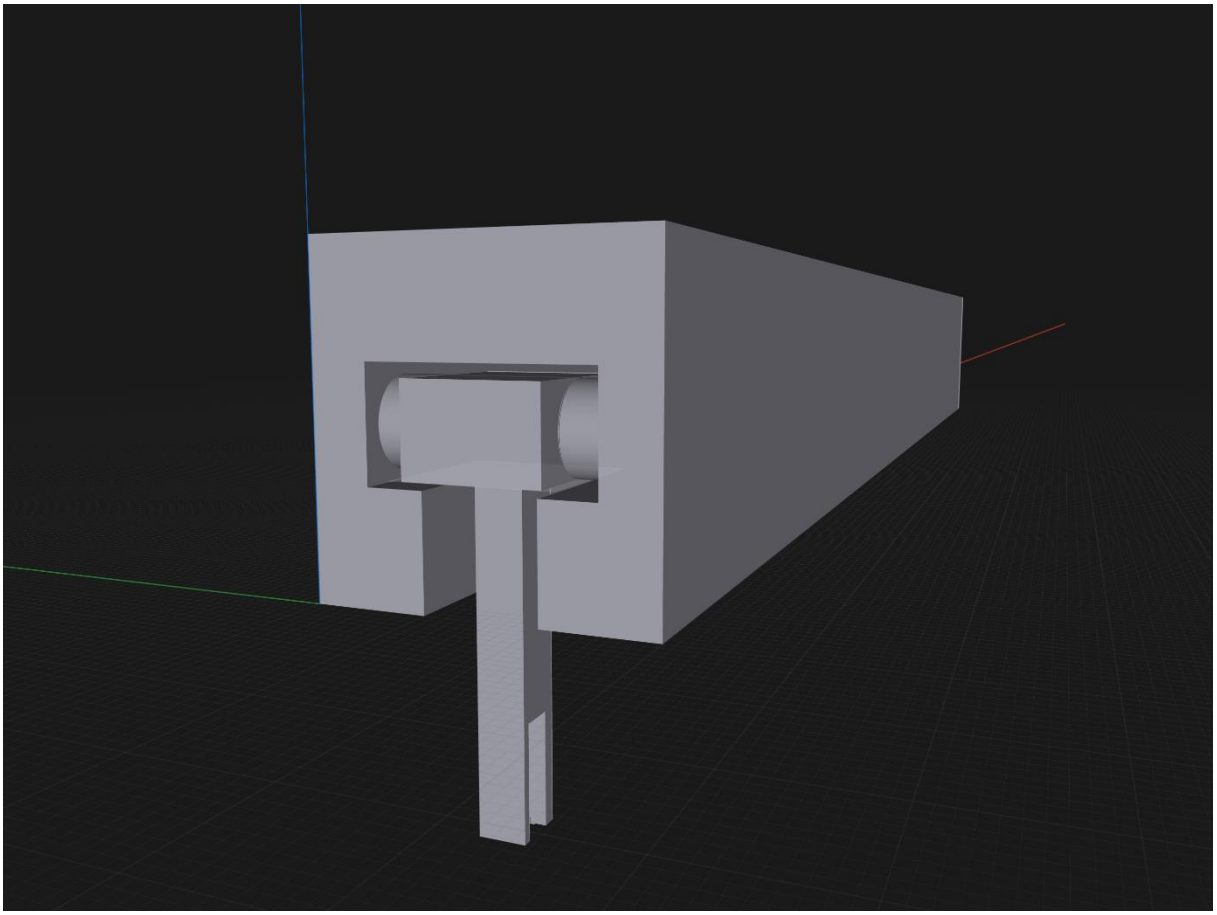

Figure 12: First Design of line structure.

Therefore this design and all connected design were deleted and the design started from the beginning with it's all parts.
Later on there will be explanation of other solutions connected with this line structure.

The reason why 1 line structure was tried to solve the system needs was to have only 1 line. The advantage of keeping only 1 line at the warehouse was to decrease usage of moving hangers and also moving particles. This design was allowing least usage of materials which would decrease the cost of the system.

4.2.2 Second Design of Line Structure (4 recesses)

Figure 13 shows how the second and final design of the line structure is designed. There are 4 recesses on the line. 3 recesses are for wheels of the moving particale to stabilize the movement in 3 directions; 1 wheel is for vertical force and 2 wheels are for horizantal forces. 1 wheel was designed to carry respect to gravity forces, since there is a gravity there is no 4^{th} wheel to carry same force direction as gravity. There is also another reason why 3 wheels is designed that according to the second line design there will be 2 lines vertically located that 1 line is for carrying hangers and the second line is for moving the hangers.

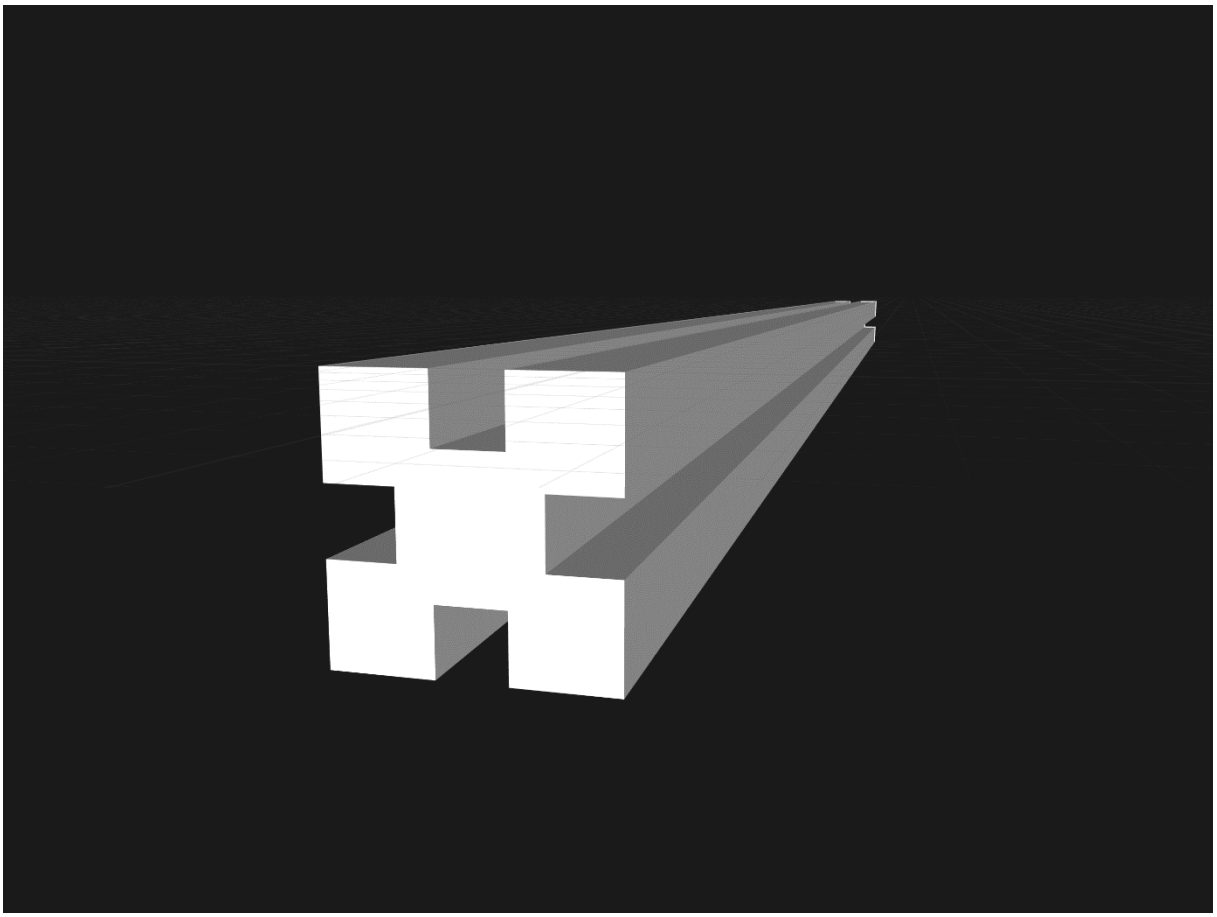

Figure 13 : Second Design of line structure.

Figure 13 design is more proper solution even though it almost doubles the expense of materials used it is more reliable and there are more capabilities, and it can decrease the possible errors would happen during moving of the particles.

4.2.3 Comparison of 2 Different Design

The difference between 2 design is significantly important for cost, production, planning and flexibility. Below table will compare 2 designs.

Single recess line (figure 12)		4 recesses line (figure 13)	
Advantages	Disadvantages	Advantages	Disadvantages
Less cost with single line	Hard to create the moving force	Easier to create the moving	More expensive, 2 line
-	Problematic turning at the corners	Easier turning at the corners	-
-	Only vertical support	Vertical and horizantal support	More expensive
Only 1 moving particle	-	-	2 moving particle cost wise more expensive
-	Not flexible for operations	More flexible for operations	-
-	Hard to solve changing the line one from another	There are possibility design C shape moving particle	-

Table 2 : Comparison of signle recess line and 4 recesses line.

Single recess is cheaper and easier to implement to project but there are problems with solution of changing the line from one to other line (switching between lines for sorting the products) and also it is harder to turn the corners, it is harder to create movement force with small space for reaching the moving particle. Therefore it is not good decision to continue with solution.

Even though this solution is more expensive and 4 recesses line will require more time for assembly of the project, production time of the materials will take more time since it is twice more materials will be used to create the lines.
It is decided that 4 recesses line is more operational and better solution for this project to create moving force and switch between 2 horizantal movement.

4.3 Forcing Mechanism of Hanger Movement

Forcing mechanism of hanger movement was designed also for first design of moving mechanism. It was difficult to solve this problem due to small space that can reach the body of the article and force the particle horizontal direction.

There will be 2 similar solutions for forcing mechanism for 2 different line design

- First Design of line structure (single recess)
- Second Design of line structure (4 recesses)

4.3.1 Forcing Mechanism for Single Recess Line

The design was made before the 4 recesses line but after it was not possible to solve some problems it became inactive for the other solutions for the problems.

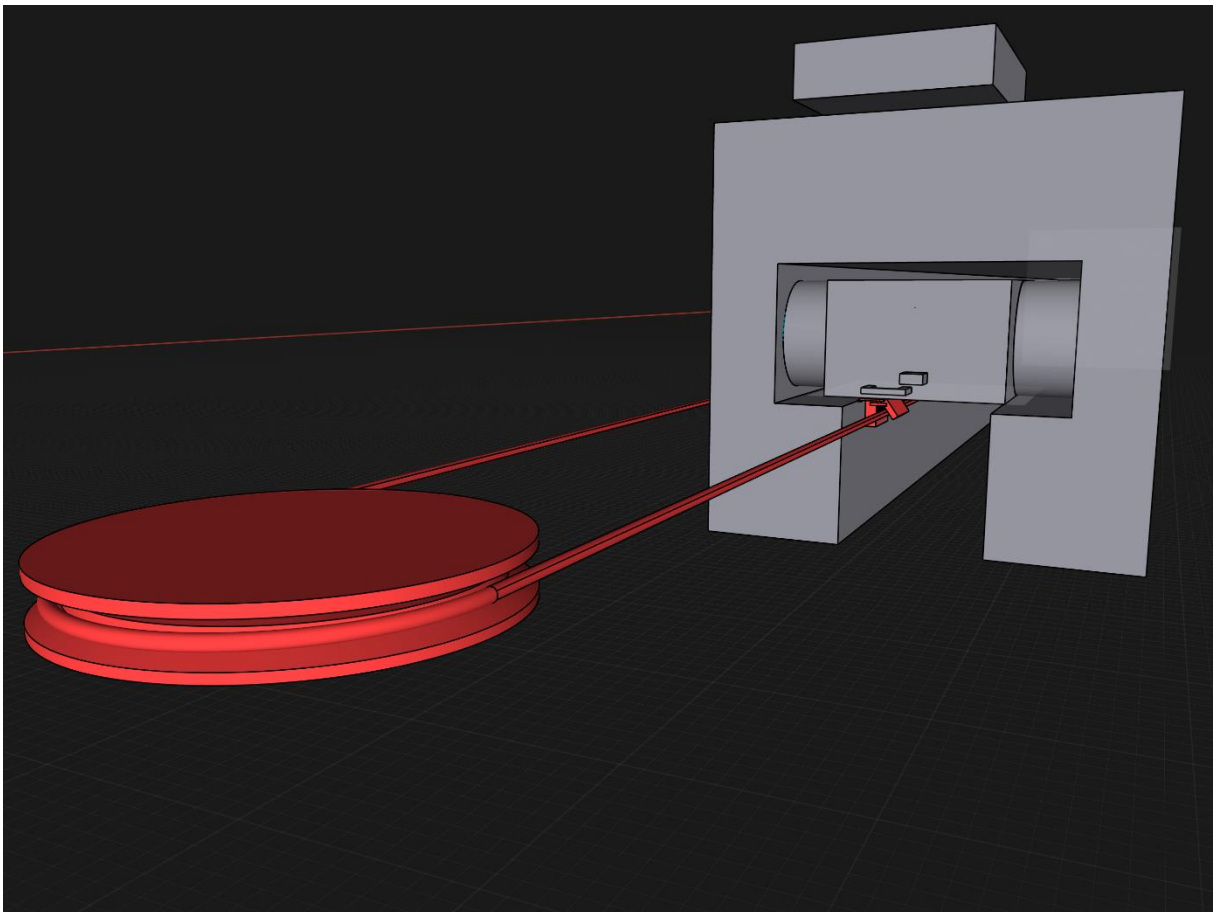

Figure 14: Forcing mechanism for single recess line.

From the figure 14 above, there is moving steel cable connected to pulley. The pulley is connected to an electrical motor (electrical motor is not added to design at figure 14) which would rotate the pulley therefore it rotates the cable. The cable is supposed to create the moving force and moving particle is supposed to catch the cable by detachable clip.

4.3.1.1 Detachable Clip Design for Forcing Mechanism for Single Recess Line

Detachable clip is designed to catch the steel cable while the cable is moving through the line and around the pulley turned by an electric motor. Catching movement is possible with a string that will force the part of the clip to fasten the cable therefore increase the friction between clip and steel cable and hold attached to the cable.
When moving particle is supposed to leave a line to another, clip should be open, that will release the moving particle free and possible to catch another cable. The way of releasing the clip mechanically (the string between 2 parts of clip is holding clip closed all the time) is designed that there will be a wheel which is connected to right side of the clip. The wheel could be pushed by a smooth offset which would than open the clip by horizontal force and finish the friction between clip and steel cable.

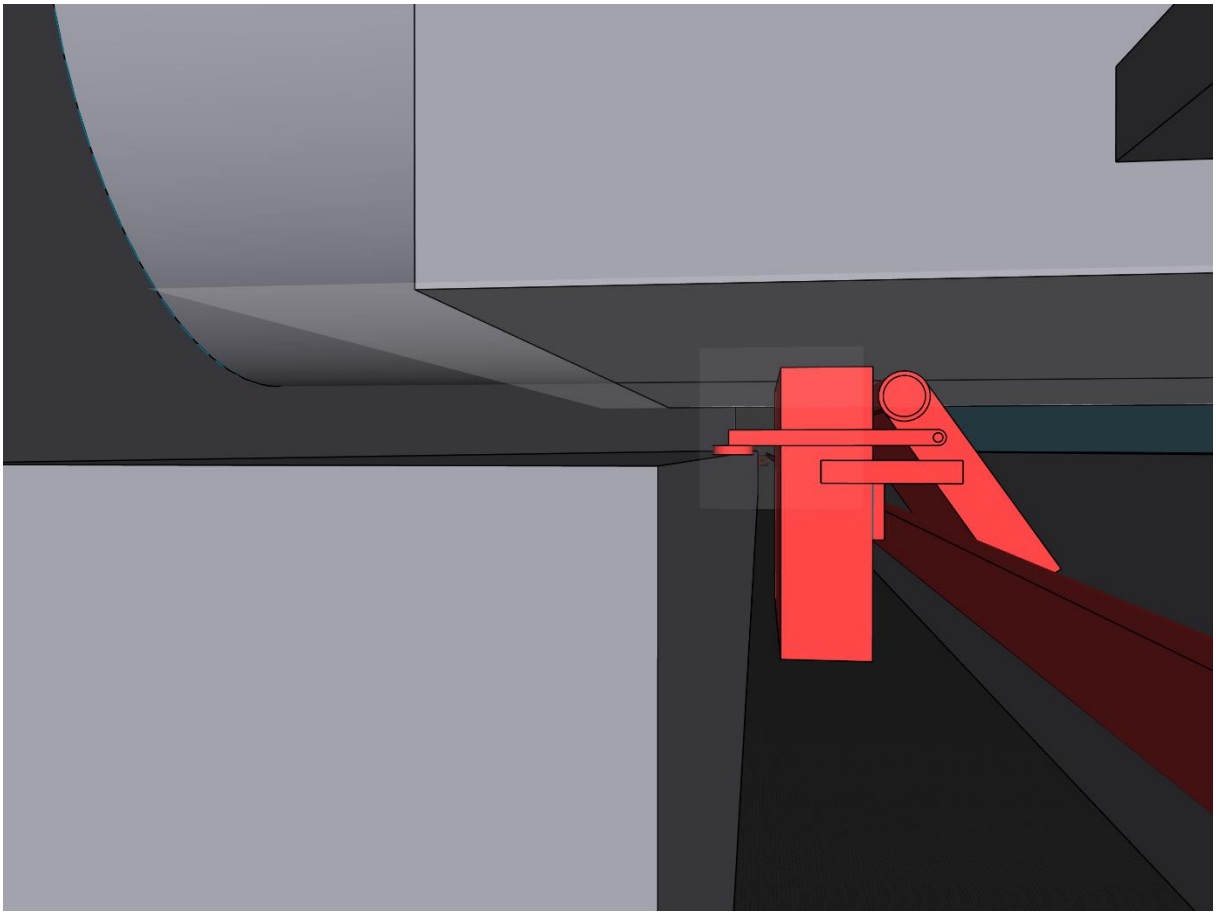

Figure 15: Detachable clip design for forcing mechanism for single recess line.

The design of the clip is inspired by ski gondola, but not all the ski gondolas have this complex design, only expensive and longer distance version of ski gondolas are using detachable clips.
Their disadvantages are that they are complex mechanisms and also it is riskier to use detachable gondolas for human safety. Their maintenance and engineering are harder than traditional versions.

4.3.1.2 Problems of Single Recess Line

Single recess line has several problems:

Creating the force movement:
Force movement was created by a steel cable with the help of rotating pulley, there is no problem with this solution, but it is hard to reach the moving particle and produce the clip with such small dimensions. Since it has small dimensions, production can be hard and clip can be easily broken. During the turning the corners it is problematic to support the cable inside because under the clip there will be products and carrying hanger therefore it is not possible to add there a supporting pulley for the cable. Even though the pulley is added for solution it will be again small dimension, it will be hard to produce and more fragile.

Switching between line to line:

Switching from line to line is a complex problem. There are not many solutions on the market for moving particles. Single recess line solution is not suitable since it is forced to move under the line. In order to switch between line to line there is necessary to cut the force which means cable and clip should be detached. After they are detached, there will be no force which would create the movement, only momentum would help it to move more. In order to switch the line system should move right or left which there is no space because both ways cable will touch to clip. There is a possibility to remove the cable from clip which is moving the cable to vertically down. But in order to do that it is necessary to support the cable when it is pushed down with a pulley but again there is no space left to add there a pulley.

Therefore, this design is not suitable for automated warehouse.

4.3.2 Forcing Mechanism For 4 Recesses Line

Forcing mechanism for 4 recesses line is designed to eliminate problems by turning the corners, shifting between lines and forcing the carrying hanger. Figure 16 is the general view of 2 line 4 recesses. It can be seen that by changing the structure from single recess to 4 recesses, carrying hanger and forcing hanger is also changed. Moving particle is changed too in order to contact with 3 recesses and support, 1 vertical(gravity direction) 2 horizontal(right and left) forces.

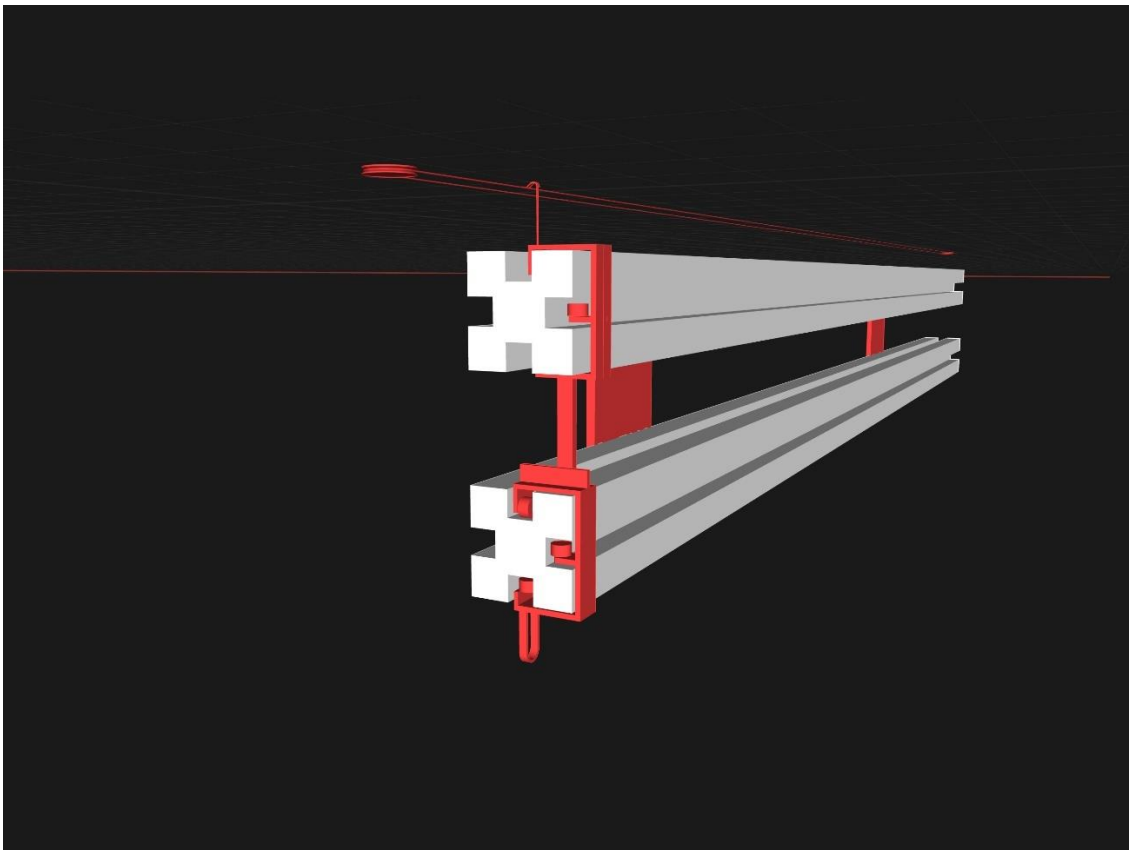

Figure 16: Forcing mechanism for 4 recesses general view.

There are 2 lines horizontally parallel to each other, distance between 2 lines is not changing that would affect the pushing force. On this design center of gravity is not in the middle of the hangers. There might be problem while pushing carrying hanger and forcing hanger but this should be understandable by producing samples and testing the movement.

4.3.2.1 Forcing Mechanism for 4 Recesses Line Front View

Forcing mechanism is designed to push the carrying hanger (upper hanger) by forcing hanger (bottom hanger). There is no connection between forcing hanger and carrying hanger, it is only by pushing force. This way of pushing it is easier to switch line because there is no continues contact. Forcing mechanism is connected to pulley and cable, pulley is rotated by electrical motor.

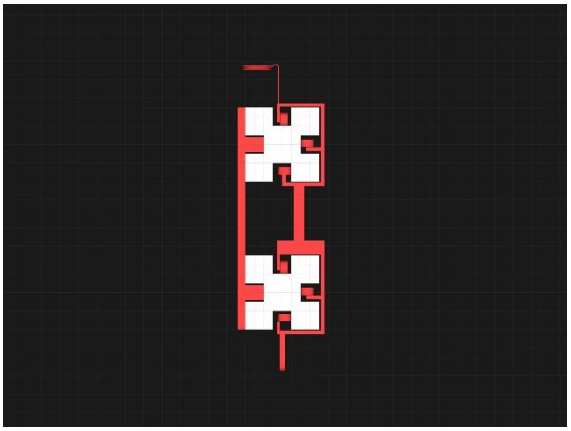

Figure 17: Forcing mechanism for 4 recesses line front view.

From figure 17, wheel angles are visible, 2 wheels are supporting horizontal forces (parallel to each other) and 1 wheel is supporting the gravity force. There is one doubt about sliding hangers upper part to the right, as if it is rotating to clockwise, since there is no support to stop this force it should be tested with prototypes that during the turns or after there is a mass on the carrying.

The solution for this problem can be applying wheels a 45 degree or less rotation, same should be applied to the structure of line, that way it might be possible to stop sliding to right side.

4.3.2.2 Forcing Mechanism for 4 Recesses Line Side View

On this side view it is possible to see that forcing hanger's (upper red part) pushing stick is not connected to carrying hanger, it is just pushing it by force

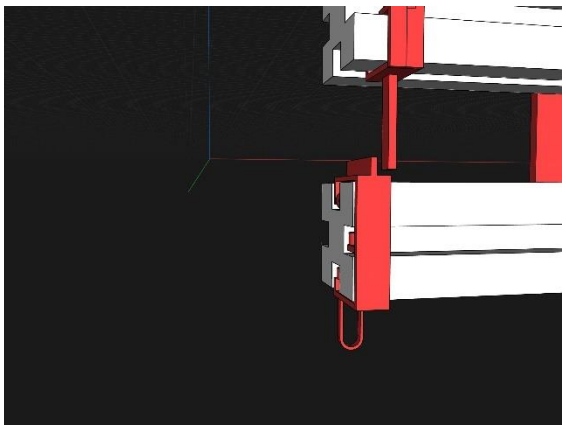

Figure 18: Forcing mechanism for 4 recesses line side view.

4.3.2.3 Forcing Mechanism for 4 Recesses Line Holding Structure

Holding 2 vertical lines was a problem, the complexity is that there are moving hangers there all the time and they have to carry products, so it is not possible to fix or stabilize them from under of the line. Same way for the upper side of the line, there is the vertical wheel which continues and moving all the time. So, it is best way to design the moving and carrying hangers as “C” shape and connect them together from the left side of the line. From those connection parts the advantage is that 2 line is always in same distance to each other. Carrying connections for those line can be done from those side connections to the ceiling or sometimes to the floor of the building.

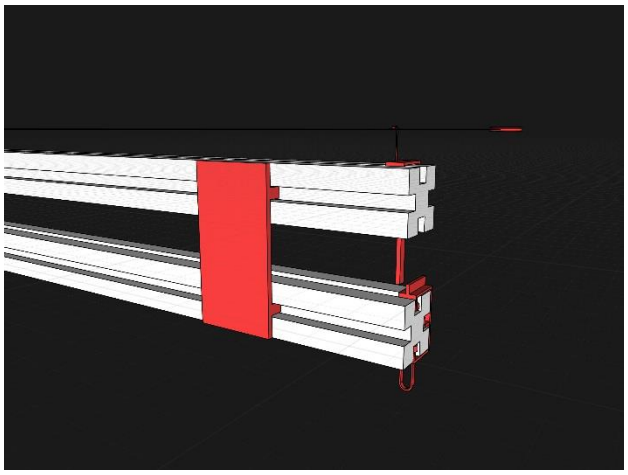

Figure 19: Forcing mechanism for 4 recesses line holding structure.

By designing the carrying hangers and moving hangers as “C” shape, problem of connecting 2 lines to each other and connecting the lines to building for immobilization reason is solved.

4.3.2.4 Connection of Carrying Hanger to Moving Cable

Connection between forcing hanger and moving cable is solved as figure 20, the design was inspired by ski gondola. Most important part here is that, when the hanger is passing through a supporting pulley, pulley must not block the movement of the hanger. Connection is allowing hanger to continue its way without blocking. Other support pulleys should be carefully mounted so that they will not block the connecting part.

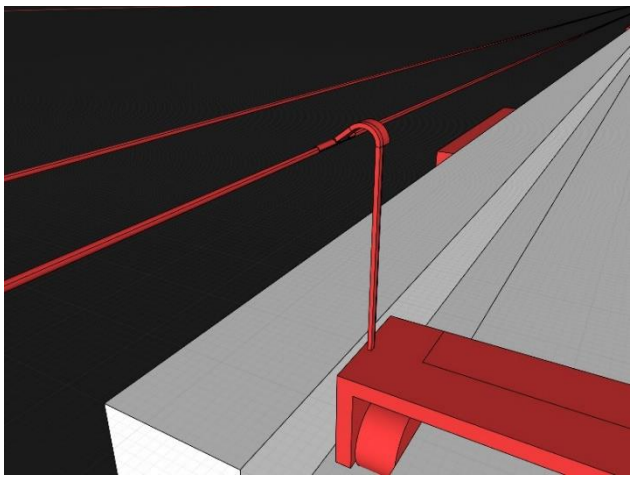

Figure 20: Forcing mechanism for 4 recesses line holding structure.

4.3.3 Switching Between Lines

There were 2 solutions introduced, single recess line and for 4 recesses line.

4.3.3.1 Single Recess Line Switching Solution Between 2 Lines

Single recess line was inactive cancelled solution however it was introduced a solution for switching from line to another. At figure 21, there are 2 moving part of the line, they are connected to a piston (not shown in the figure 21). Those moving parts are deciding which line the moving particle will continue to move. The force which would give the motion to moving particle was created by gravity, after the line is decided, moving particle was supposed to catch again the cable with clip and keep moving.

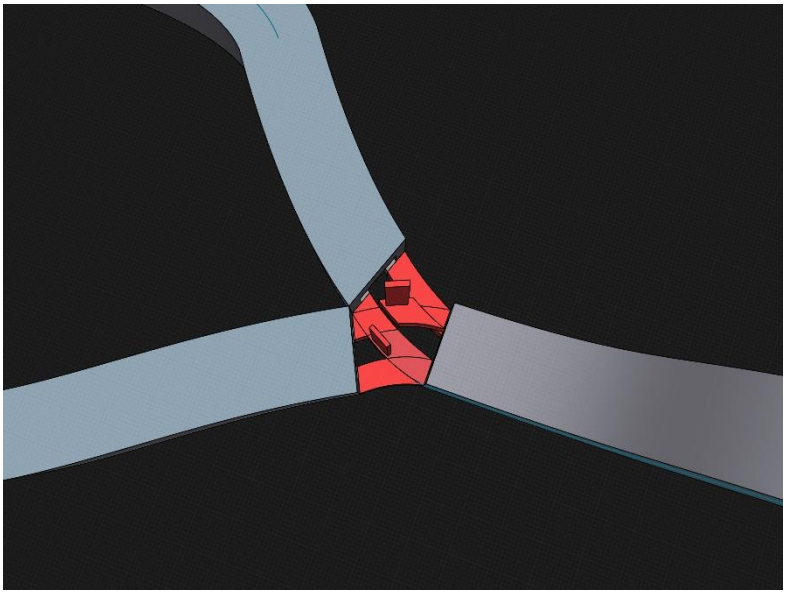

Figure 21: Single recess line switching solution top view.

The shift was solved by moving those 2 parts, when one part is connected (pushed down by a piston), other part is pulled (pulled up by a piston) so that way moving particle would have only one way to follow. But this design was cancelled for several reasons which were mentioned at part 4.2. 3..

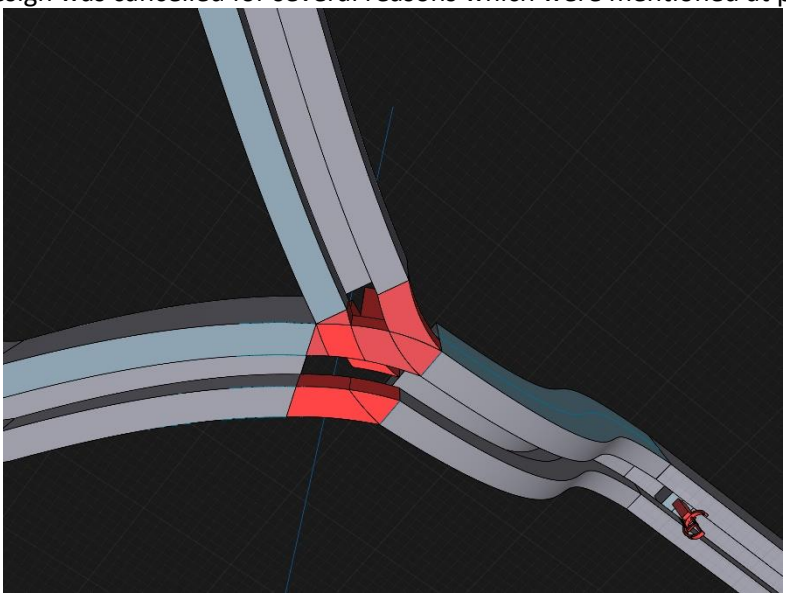

Figure 22: Single recess line switching solution bottom view.

4.3.3.2 Four Recesses Line Switching Solution Between 2 Lines

The design of the shift between lines is solved by adding there a moving separated line between 3 lines. When separated line is open (as shown in figure 23) carrying hanger is supposed to change to turning line. When separated line is closed (as shown in figure 24) carrying hanger will continue to the straight line.

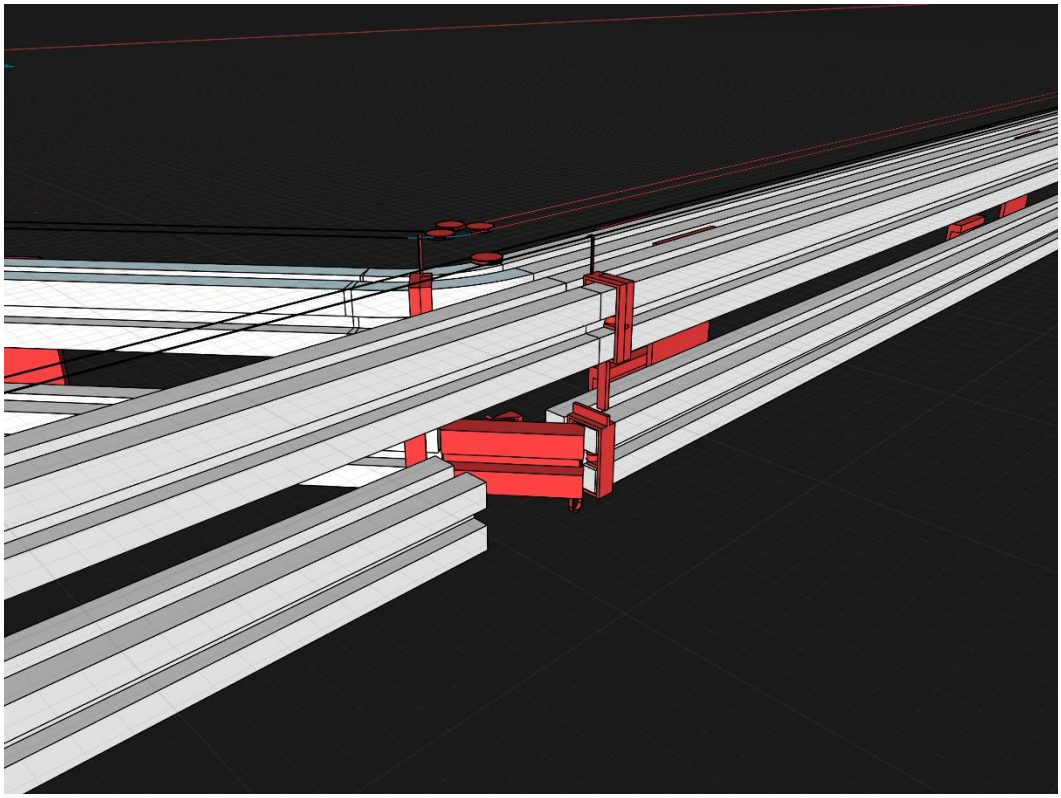

Figure 23: General view of switch solution on 4 recesses line

When Separated line is closed it will look like the figure 24. In order to get this position, there will be 2 pistons to adjust 2 exact positions. First position is closing position and other position is open position. Separated line will rotate and move forward because of it is shape.

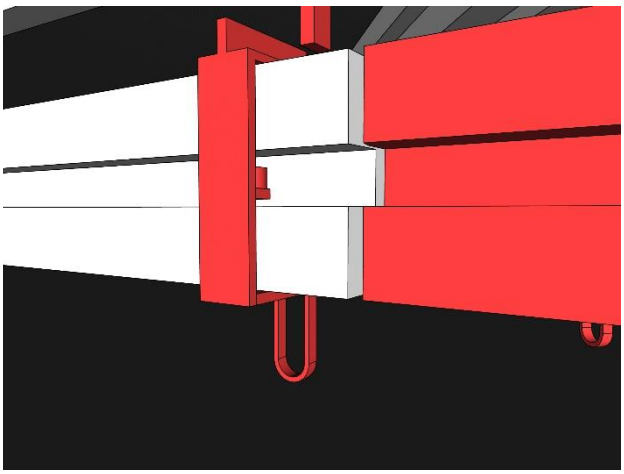

Figure 24: Separated line closed.

When separated line at open position carrying hanger should move from main line to separated line smooth. Shifting from line to line there are small spaces, in order to increase the smooth passing, the gap can be decreased. The gap distance should be maximum same as the radius of the moving particles wheel. Figure 25 is after carrying hanger has passed the separated line, switch between lines is completed.

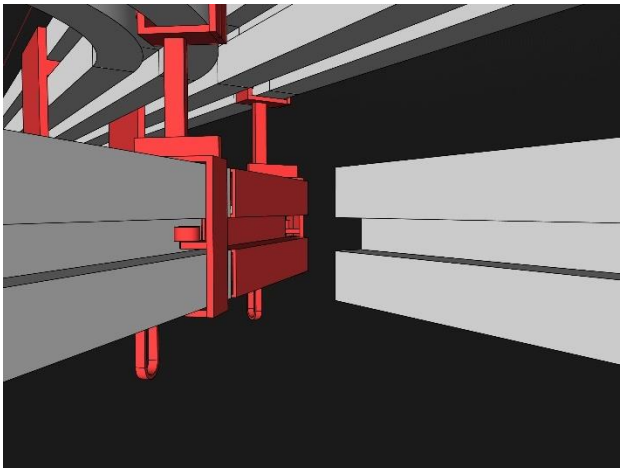

Figure 25: Separated line open position front view.

Back side of the separated line at open position is shown at figure 25, there should be 2 pistons moving the separated line from open to closed position (it is not shown in the figure 25 and figure 26).

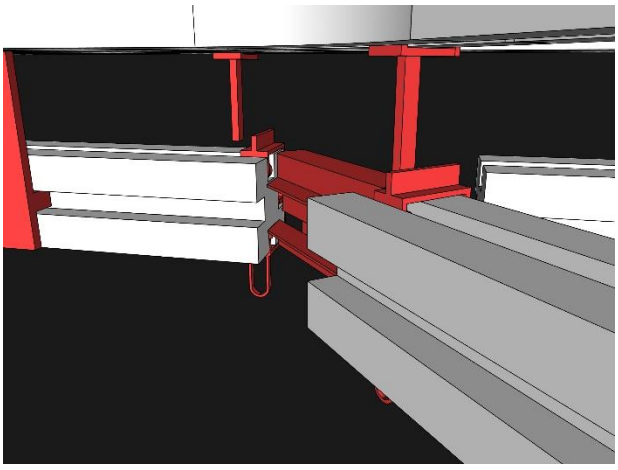

Figure 26: Separated line open position back view.

On this switch design there are 2 points can be done better:

First one is that there are 2 pistons which should close and open the separated line, it should be solved by creating a turning center connected to straight line and moved with only 1 piston. Mentioned improvements should increase the precision of location and speed of closing and opening the separated line.

Second point to improve is the angle between straight line and switching line. In order to decrease the gap, it is also necessary to decrease the angle, that way lines will get closer to each other.

4.3.4 Hook Catch/Release Design

First design (figure 27) was single recess therefore first version was designed for single recess. There is a stick opening and closing for holding the product, but that version is cancelled due to insufficient solution.

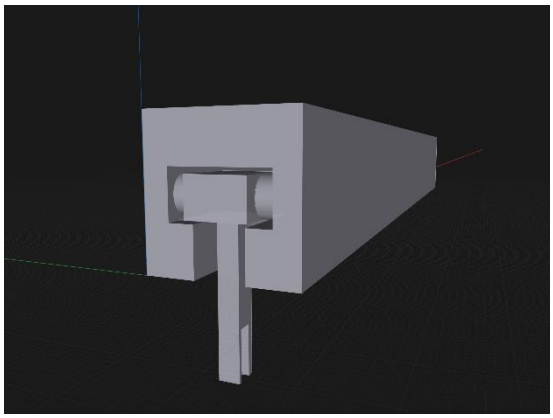

Figure 27: single recess catch release.

Figure 28 shows the second version, a piston is supposed to push the line vertically up to down that will open the gate and drop the product, but this version is unnecessary complicated and also the line is completely closed it is hard to find the space to reach the stick which needs to be pushed down. Insufficient design therefore version 2 is cancelled.

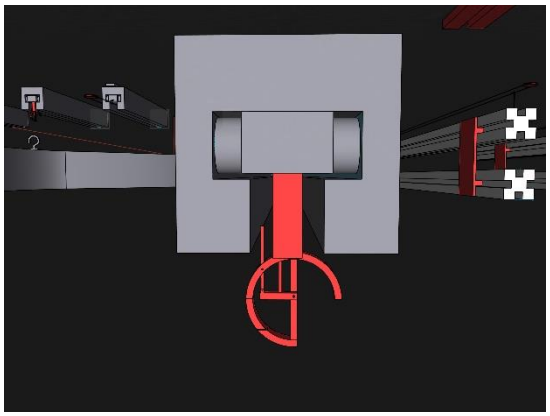

Figure 28: single recess catch release version 2.

Version 3 of catch release is easier design, the top part of the catch release should be pushed vertically down to drop the product. After pushing force is returned catch release should return its initial position by a string as shown at figure 29. Hard to reach to push trigger to drop the products. Insufficient design for the problem therefore version 3 is cancelled.

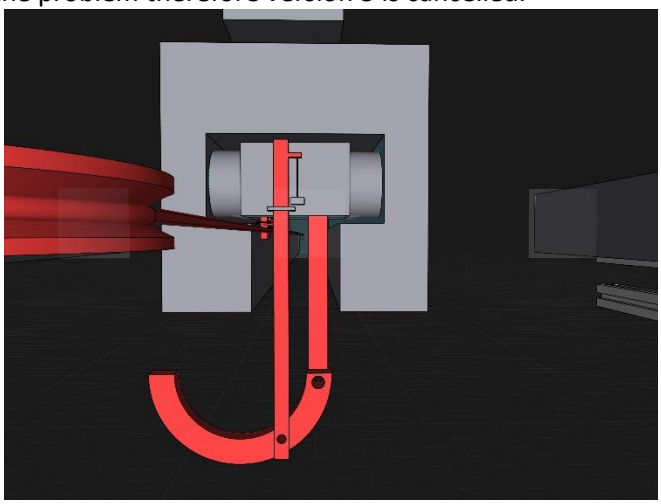

Figure 29: single recess catch release version 3.

Final confirmed solution is figure 30, it is compact, easy to produce, there is no mechanical movement on the catch release. The cost of the mechanism is lower than other designs. Products are hanged to the mechanism and removed from there, so it is not necessary to create self-moving mechanism.

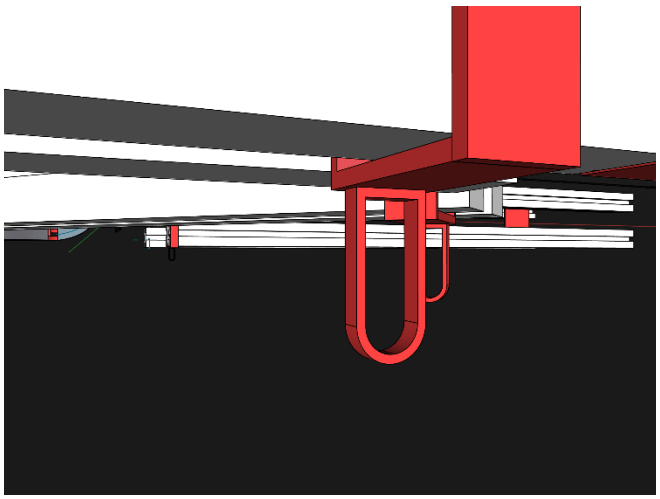

Figure 30: 4 recesses catch release.

Catch and release can be achieved by designing a unit where products will be assigned to carrying hangers. The logic should be that diagonal (vertical up and horizontal right) movement will catch the product, used mechanism will be as figure 30. In order to release the product carrying hanger will move diagonal again but counter direction (vertical down and horizontal left). That way will decrease the cost by creating this unit for only necessary locations (mechanism itself will not move) so that cost of carrying mechanism will be low cost.

5.Conclusion

The study will reach to a conclusion in this chapter, which will summarize the important results in connection to the research goals and questions and consider their importance and contribution. Moreover, it will discuss the study's limitations and suggest topics for additional research.

The design of an automated warehouse for hanging products has been completed with general 3D design and solving technological particles of the system. The focused problems of the system were divided to 3 parts, forcing mechanism of hanger movement, switching between lines, hook catch/release design. Solving switching between lines and creating moving force was the most complicated part of this thesis. The aim of this thesis is to investigate existing solutions of other companies which are on the market and improve the project for middle-sized companies that they can also use automated warehouse in order to compete to send more products per unit time and be able to sell lower prices of their products by lowering logistics cost.

Designing 3 technological solution was connected to each other. The design of forcing particle, line structure of aluminium and switching between line solution was changed many times. From this study it can be understood that projects can start from the beginning many times when there is an obstacle to move forward to next step. It is important to organize the time management of the project as considering that the design can be wrong at all. During the market research of existing companies' solutions, they are not showing on their company websites or marketing videos how they solved switching between lines. This study can help others to solve similar mechanical problems at least as an idea and possible solutions with its problems. So that they can use the design, acknowledge the current work and start their projects with proper ideas.

Final designs were considered that they will work in real life but those designs should be tested by prototypes. Lines should be tested if moving particle is moving without stopping though an offset or a curved line. Switching between lines should be seen in real life how fast and without a problem the moving particle will transfer from line to line. Finding way to solve forcing movement with single line instead of 2 lines, would have decrease the cost of materials used on this part in half. Therefore, automated warehouse can reach to more companies for financial reasons.

For future research it is necessary to produce the solutions in real life instead of a computer-based design and be able test it and analyse the problems from real applications to improve and continue the study. In order to reach more companies to use automated warehouse and decrease the cost of the system unit solutions should be developed. Unit solutions can eliminate expensive reengineering, unit solutions can decrease the project time and cost.

Finally existing solutions are mentioned, designs for given tasks are solved.

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List of Electronical Attachment

All attachments are available on the CD.

Attachment 1: Automation Warehouse General 3D Design.dwg
Attachment 2: Focused Mechanisms 2D version.dwg