Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Modernisation of Furniture's Packaging Line by Implementing Automated Systems

Master's Final Degree Project

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Lect. dr. Darius Mažeika

Supervisor

Kaunas, 2020

Kaunas University of Technology

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Industrial Engineering and Management (6211EX018)

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Modernisation of Furniture's Packaging Line by Implementing Automated Systems

Declaration of Academic Integrity

I confirm that the final project of mine, Donatas Brundza, on the topic "Modernisation of Furniture's Packaging Line by Implementing Automated Systems" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Modernisation of Furniture's Packaging Line by Implementing Automated Systems

Given to the student – Donatas Brundza

1. **Title of the project –**

Modernisation of Furniture's Packaging Line by Implementing Automated Systems

(In English)

Baldų pakavimo linijos modernizavimas diegiant automatines sistemas

(In Lithuanian)

2. **Aim and tasks of the project –**

Aim: design a furniture packaging line with automated systems which performs up to 23 boxes/min.

Tasks:

1. Analyse existing packaging lines in furniture companies, evaluating the impact of automated systems for capacity and profit.
2. Design automated packaging line considering the requirements of capacity (*23 boxes/min*), automated box folding, closing, panel insertion, unloading tasks and placement in designated hall (*Appendix 1*).
3. Evaluate financial payback duration for designed packaging line, which must be reached within 5-year period, and expected loss-profit calculations.

3. **Initial data of the project –**

Packaging line must perform up to 23 boxes/min; Economic payback must not exceed five-year period; The line must fit to designated hall (*Appendix 1*);

4. **Main requirements and conditions –**

SolidWorks, Microsoft Office365, Machine directive (*2006/42/EB*)

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Supervisor	Lect. dr. Darius Mažeika		
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Brundza Donatas. Modernisation of Furniture’s Packaging Line by Implementing Automated Systems. Master's Final Degree Project, supervisor Lect. Mažeika Darius; Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

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Summary

Packaging lines are one of the key factors of today’s industrial companies, as it defines the outcome of manufacturing. Though some industrial fields have implemented automated packaging systems, which lead to high capacity rates, this is not the case when considering the furniture industry. Only a small amount of furniture companies has installed high performance automated packaging lines, which allows to presume that implementation of such systems in the furniture industry can be considered as a novelty. The main goal of this research was to design a modern packaging line with installed automated systems applying newly developed solutions and existing methods of furniture industry companies. The experience that the companies have compiled across the years, provides crucial data which can be related and based on for further future improvements. Newly designed solutions, such as the robot cell and the automated outfeed system, have made it possible to eliminate monotonous physical work, thus automating low added-value workplaces. This study shows that the application of automated packaging lines in the furniture industry would provide an opportunity to take a step towards a modern industry field. And this would not only increase the capacity, but also have a positive impact on the company's financial results.

Brundza Donatas. Baldų pakavimo linijos modernizavimas diegiant automatines sistemas. Magistro baigiamasis projektas, vadovas doc. dr. Darius Mažeika; Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

Reikšminiai žodžiai: Baldų pakavimo linija, roboto celės, automatizuotos sistemos, gamybinis pajėgumas.

Kaunas, 2020. 69 p.

Santrauka

Šių dienų pramonės įmonių gamybos rezultatui didelę įtaką turi pakavimo linijos, kurios apibrėžia gatavos produkcijos kiekį. Tam tikros pramonės sritys, turinčios visiškai automatizuotas pakavimo sistemas, gali pasiekti maksimalų darbo našumą, tačiau baldų pramonė nėra viena iš jų. Tik nedidelė dalis įmonių yra įdiegusios didelio našumo ir aukšto lygio automatizuotas pakavimo linijas, todėl tokių sistemų pritaikymas tampa inovacija didžiajai daliai baldų pramonės įmonių. Pagrindinis šio tyrimo tikslas – suprojektuoti modernią pakavimo liniją su įdiegtomis automatizuotomis sistemomis pritaikant naujai sukurtus sprendimus ir esamus baldų pramonės įmonių metodus. Automatizuotos sistemos buvo parinktos atsižvelgiant į sistemų tinkamumo analizę ir iškeltus pakavimo linijos reikalavimus. Naujai suprojektuoti sprendimai, tokie kaip robotų celė detalių įdėjimui bei automatinė nukrovimo sistema, leido pašalinti monotonišką fizinį darbą taip automatizuojant mažą pridėtinę vertę kuriančias darbo vietas. Šis tyrimas rodo, jog automatizuotų pakavimo linijų pritaikymas baldų pramonės įmonėse suteiktų galimybę žengti žingsnį modernios pramonės link. O tai leistų padidinti ne tik gamybos našumą, bet ir turėtų teigiamos įtakos įmonės finansiniams rezultatams.

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Introduction

Various industry fields are vital factors for most countries, as it impacts gross domestic product. Comprehension of industry importance is crucial. Generally, industry in Europe increases up to 3.2% every year and considering today‘s Industry 4.0, this percentage could increase even more. When it comes to Lithuania, the furniture industry has been a part of constant economic growth for a long time. Taking into account last five years, Lithuania was the best performing market in Europe for furniture production growth, mainly driven by exports (*13 % of Lithuania's total export*), making up to 8 % of Lithuanian GDP yearly. This has been a result of continuous improvement in efficiency, capacity and other factors [1].

Considering that the furniture industry has been developing over the past years, many innovative solutions were implemented, which allowed this rate of growth. However, this rate could be increased even more if a regular issue of packaging performance rate would be solved.

Automated packaging systems in the furniture industry are rarely found due to big investment size and the fact that the articles require flexibility, which is not always found with these kinds of systems. Nevertheless, correctly implemented systems could make a big impact in a company's outcome.

This paper reviews the current situation in some of existing furniture companies with analysis and development of possible solutions which can be applied in the furniture industry. Design of complete packaging line with implemented automated systems is explained and based on calculations or other data, which was gathered during this research.

Aim: Design a furniture packaging line with automated systems which performs up to 23 boxes/min.

Tasks:

1. Analyse existing packaging lines in furniture companies, evaluating the impact of automated systems for capacity and profit.
2. Design automated packaging line considering the requirements of capacity (*23 boxes/min*), automated box folding, closing, panel insertion, unloading tasks and placement in designated hall (*Appendix 1*).
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1. Relevance of the research

Automation in industries plays a vital role by using machines ”intelligently”. Minimal human intervention is the goal that pushes to adopt automation in industries. Automation is a modern approach to how things can be managed differently. Implementation of such systems creates a possibility to produce high-quality goods for consumers, generate a higher return on investment for the investors, and bring safety to a workplace [2]. Automation is a necessity in industries because it not only seeks to improve the quality of life for humans both at home and at work, but also allows the distribution of quality products and services to be made available at higher performance rate. It is what is currently promotes the world's distribution chains [3]. The industrial sector is essential to every countries' economy and remains the part which has a high impact on economic growth and employment. Industry, which in this context focuses on manufacturing, provides added value through the transformation of materials into products [4]. And according to numbers, industrial sectors fully follow and understand it, as according to official IFR (*International Federation of Robotics*) Press release, robot implementation has continuously been growing through the years. The forecast for annual growth reaches over 10%, as the graph in Figure 1 indicates. Also, implementation of novelties such as IoT[1] provides possibilities of controlling and monitoring a complete system of machines with data collection [5]. Capacity, downtimes, adjustment times or malfunctions can be monitored and analysed with a use of IoT system. Performance rate, downtimes, adjustment times are vital data which can be analysed and make basis for grounding various decisions [6].

For manufacturers, it is hard to maintain with the continually increasing pace of market growth as the demand increases. Often the biggest issues are - bandwidth limitations and labour, and the packaging line automation is an excellent place to eliminate it [7]. Determining the time when the investment for automated system implementation is correct, adequate research and calculations must be done [8].

Fig. 1. Graph of annual industrial robot installations worldwide [9]

[1] IoT – Internet of Things

1.1. Markets and Demand in the furniture industry

To be competitive, understanding the furniture market and analysing a potential growth of it, may help to see what is expected in the future [8]. Having this information provides a basis for deciding whether current status of a packaging line can cope with future perspectives or not.

"Global furniture market is anticipated to gain high momentum in the projected time frame supported by growing infrastructural investments and economic growth of various developing nations "– states Pulidindi K. and Pandey H. In their furniture market report [10]. The rate of growth can be influenced by many factors that may be thought of non-linked ones. For example, increasing rate of apartment construction, developing countries are growing and turning to improve their living conditions. To add on, the higher standard of living [11] allows more people to apply changes in their domestic appearance, which causes higher rates of change over for furniture. According to 2018 data, furniture market size was 576,31 Billion (USD), and by 2026, it should reach nearly 900 Billion (USD) [10]. A constant 5.5 % annual increase rate shows sustainability and performance which can be taken as a grant not only for the furniture retailing companies but also for furniture manufacturers, machine manufacturers, investors and others. Furniture industry is one of the steadiest growing industries which provides a big part of GDP for some countries, one of them is Lithuania. If analysing the market share in 2018 for furniture by country, Figure 2 shows that China takes the leader place with 94 Billion (USD) [12].

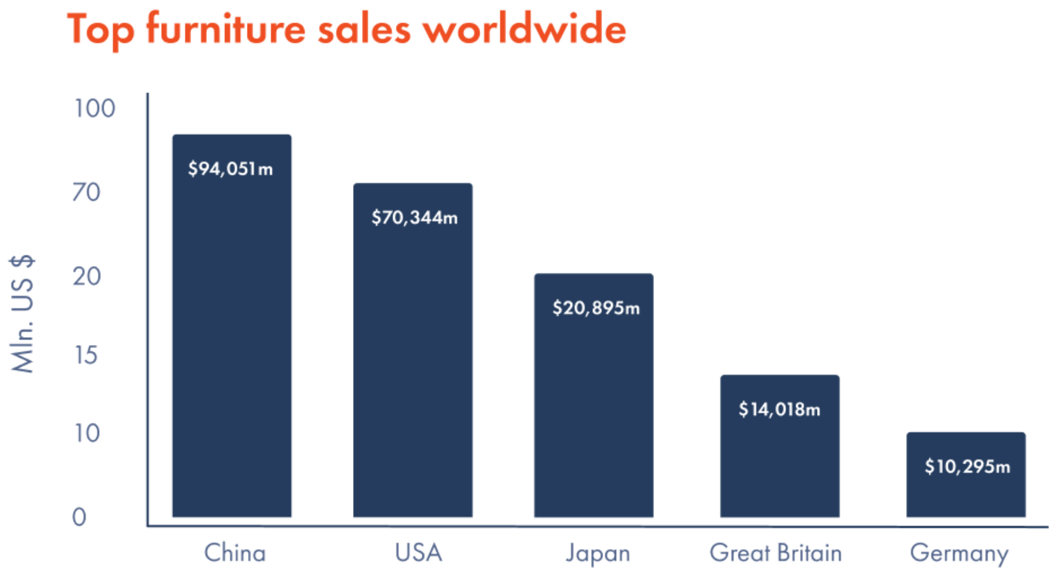


Fig. 2. Comparison of furniture market share in 2018 [12]

1.2. Labour Cost Vs Automation Cost

Reducing manual labour costs is one of the key benefits of automation. However, high initial investment has reduced the number of implementations. Despite other pros, automation has allowed industries to increase efficiency and reduce long-term costs. For example, a case study in an industrial company showed that once replaced 2 out of 4 workers with automated system, 3-year savings reached up to 86 000 Pounds. Also, second-year indicated 83 000 Pounds of ROI[2] [13].

[2] ROI – Return On Investment

However, there are other items to be considered in comparison of labour and automation costs. While training costs and taxes are decreased once implemented an automated system, maintenance and additional direct costs increases. On the other hand, eliminating human error can increase quality and reduce risk of injuries. Of course, not every area is required to be automated, as of technical possibilities, cost and other circumstances. Every position should be analysed and calculated whether the automation will give the positive feedback as required. Substantiation should be based on economic calculations which relate to an investment payback period. It is thought that investment should be useful if the payback is within a period of 3 to 5 years, depending on an implementation field, size and other factors [14]. Figure 3 displays an example of how various costs distributes according to a manual and an automated process. Conclusions can be done that automated process provides high-performance rate, which increases raw material costs. [15].

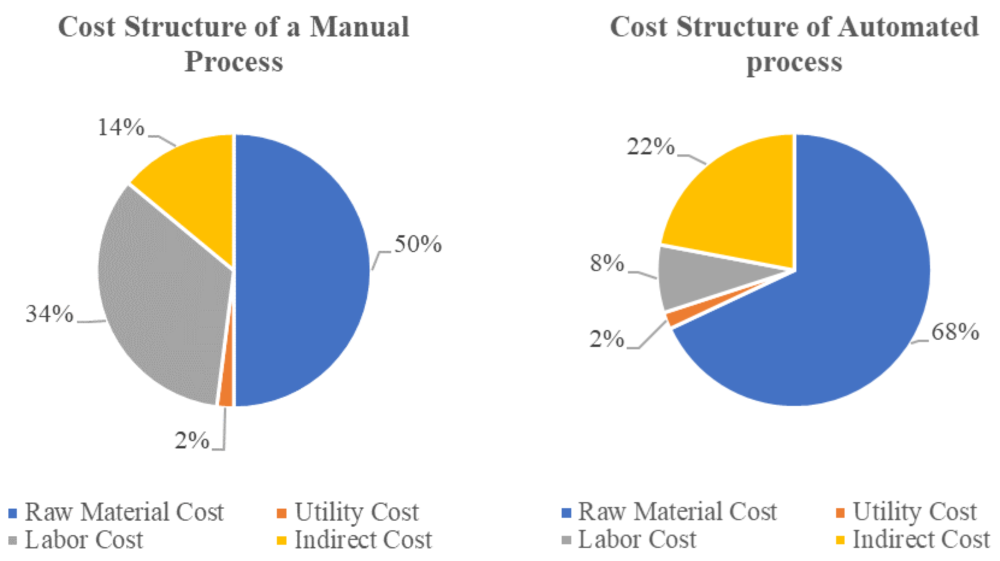


Fig. 3. Cost Structure example of Manual Process vs Automated Process in Germany [15]

1.3. Health care and repetitive operations including physical labour

Manual labour in a packaging line consists of hard and monotonous actions that need to be performed for an entire duration of a shift. Many tasks consist of tedious, repetitive motions which also involve non-convenient or problematic working positions. When a certain limit is reached, a worked is not able anymore to perform as expected. An employee cannot maintain a high rhythm for an extended period once the pace has exceeded his limits. This is due to constant improvement in production rates, efficiency and capacity. Increased demand pushes the bandwidth area to a limit, and this causes stress in a working environment. In circumstances like this, risk of injuries and a rate of worker change-over is increasing. Additionally, repetitive work consists of one or a few simple operations that are repeated so quickly or for such a long time that it can cause muscle and skeletal pain [16].

Because of these or similar conditions, automation solutions are being implemented which allow to not only remove the tedious and monotonous manual labour but also create additional added value by increasing the performance rate and efficiency. Robots or other automated systems can perform the same tasks over time with the same consistency, speed and quality. Especially dealing with repetitive operations, robots' performance is the most noticeable [17]. Intelligence, focus on safety, flexibility, versatility and collaboration are factors that robots and automated systems are able to offer [18].

2. Analysis of existing packaging lines in furniture companies

Packaging line can be described as a sequence of machines in a line, performing adequate tasks, a conveyor with people for manual labour, or a combination of both. Various packaging lines can be found across different industry fields, as particular materials or objects are being made, transported, sorted and packaged. Additionally, even in the same field of industry, two companies most likely will have different packaging solutions because of space, logic, range and financial opportunities.

Comparison between different packaging lines can be complicated, as different companies have different materials, dimensions, weights, etc. As smaller and lighter articles can be packed in higher production rates than bigger and heavier ones. However, analysis can provide essential data and knowledge of solution which have been implemented over time to increase both production rates and level of automation.

When it comes to the furniture industry, packaging lines mostly consists of same essential elements – box folding area, pick-and-place area, box closing area and wrapping area [19]. These areas may vary accordingly to the company needs, though the basics remain similar. However, theoretical presumptions are not always fully applied in real-world situations. For this reason, an analysis of several existing packaging lines allows to consider and evaluate what solutions are involved and make presumptions on what could be improved. Examination of existing packaging lines were done in two companies: SC "Freda" and JSC "Baltic Furniture Components".

2.1. Packaging line in JSC "Baltic Furniture Components"

JSC "Baltic Furniture Components" mainly aims to a drawer fronts of various kind of furniture. While not manufacturing complete furniture, the company offers flexibility in manufacturing by individual orders maintaining high production rate [20].

As the company is based on individual orders in different batch sizes, it must cope with fast change over time as articles might come in various shape and measurements. However, this not only relates to the overall production of the components but also the packaging. Smaller batches and wider article range means that flexibility is one of the essential features that they must fulfil and keep in high priority. The issue with this type of business model is that the automation question becomes a difficult choice since costs for flexible automated systems can be up to 70-80 % higher when compared to regular. Though there are possibilities and examples ("*Nobilia GmbH", JSC "Schmid Cuisine"*) for automated batch-size-one production and packaging, the implementation level of such kind of systems are still deficient.

At the moment, JSC "Baltic Furniture Components" works with simple semi-automated packaging line. The machine which was installed has three main functions – box folding, panel insertion, box closing. As the machine is not equipped with material loading or unloading, overall, three workers are needed for operation.

The packaging line is formed in a T-shape with two colliding flows (*Fig. 4*). The shape is adopted to the place in which it was installed, and this allowed better material flow and more efficient space utilisation.

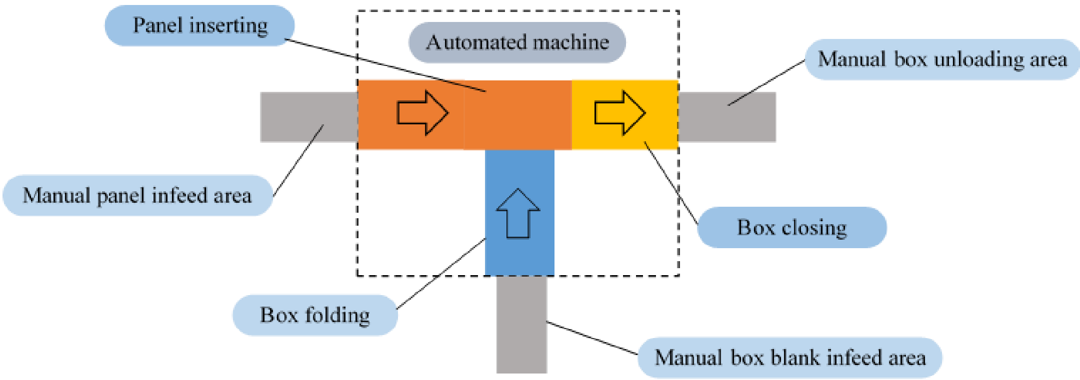


Fig. 4. Layout of JSC "Baltic Furniture Components" packaging line

One of the flows begins in the panel infeed area. In this area, worker places panels inside a magazine which doses the panels one by one on a conveyor. From here, the panels are being transported under a vacuum gripper, which then picks it up and moves to panel inserting area and places inside a folded box.

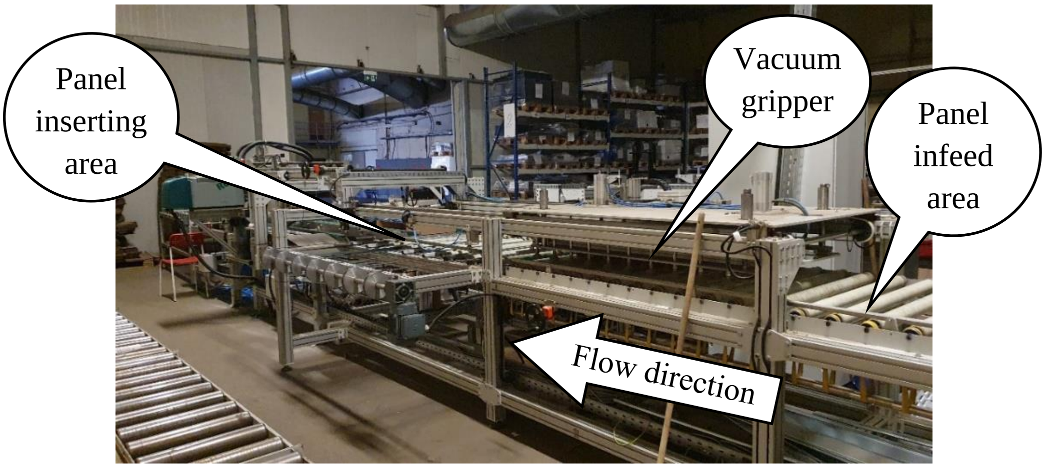


Fig. 5. Panel infeed and inserting stations of JSC "Baltic Furniture Components" packaging line

The other flow starts in the box folding station. This station consists of belt conveyor which automatically moves box blanks to the folding area, where a box is shaped into form. Material is stacked on a specially designed magazine which distributes blanks one-by-one.

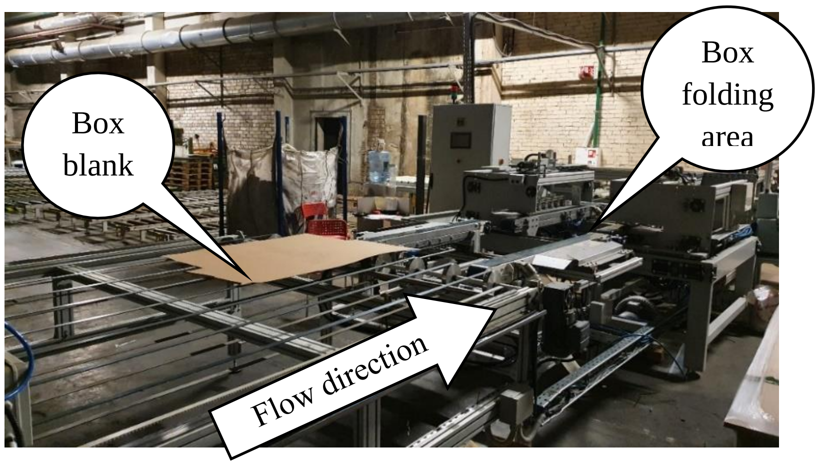


Fig. 6. Box folding station of JSC "Baltic Furniture Components" packaging line

Once a panel is inserted in a box, it is transported to the box closing station, where a top box lid is glued and closed. Closed boxes are transported via conveyor to the unloading area, where worker manually takes out the boxes from the machine and stacks it on a pallet.

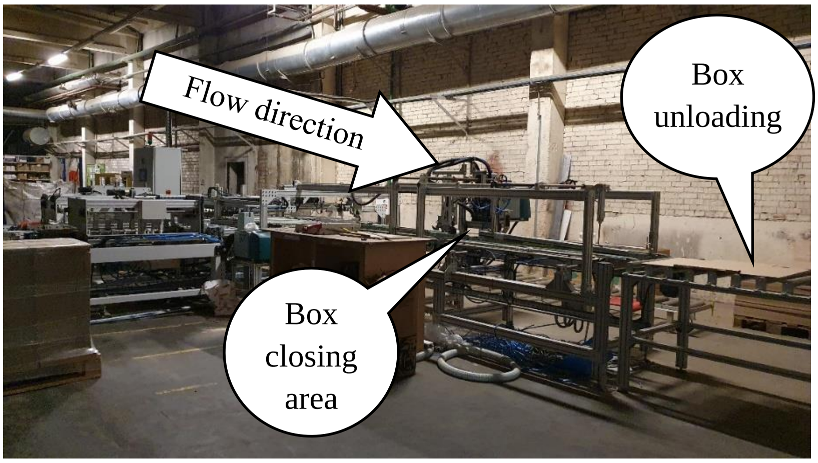


Fig. 7. Box closing station and manual unloading area, JSC "Baltic Furniture Components" packaging line

The complete line is capable of packing boxes with length of 300-900 mm, width of 300-600 mm and height of 40-100 mm and maximum weight is up to 10 kg. The machine is capable to output capacity up to 6 boxes/min. As the most extended procedure is the box folding, the dimensions of box does not make an impact for the machine performance. The machine was installed to automate and replace fully manual packaging line. With manual packaging line, it was possible to reach capacity up to 3,6 boxes/min with six workers. When calculating general capacity improvement, the production rate has increased by 66,7 %. Also, when considering monthly costs for workers, savings can be calculated too. If taking an average 1500 Eur. (*Gross*) per month wage, overall costs were 9000 Eur./month. With automated machine implementation, the worker number reduced to just only three. That allowed to reduce the salary to 4500 Eur./month (*per shift*). The automated machine allowed not only to increase production rates but also to minimise salary expenses by 50 %, while the total investment size was 200 000 Eur.

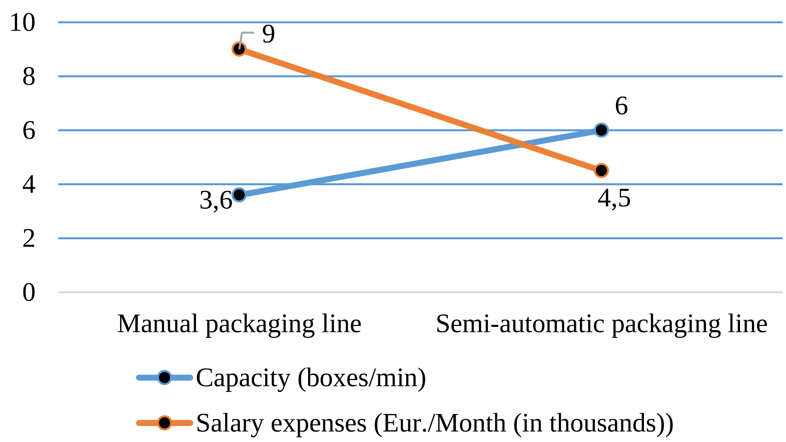


Fig. 8. Graphical illustration of capacity and salary expenses with manual and semi-automated packaging line, JSC "Baltic Furniture Components"

Figure 8 illustrates the change of capacity and salary expenses between manual and semi-automated packaging lines when automated systems were implemented.

2.2. Packaging line in SC "Freda"

SC "Freda" is one of the oldest furniture company in Lithuania that is aimed in flat-pack furniture from particleboard, MDF[3] and honeycomb panel. [21].

The existing packaging line has transformed several times in the last years due to modifications that company has implemented. As from the beginning, the line was entirely manual. However, the increased efficiency and market demand, forced to take additional actions to reach higher productivity. And this lead to be one of the leading companies (*Fig. 9*) in the furniture industry. "Kaunas furniture SC "Freda", when compared profitability, return on assets and working capital management indicators, according to 2018, financial results were greater than other European IKEA suppliers" – article claims [22]. These recognition claims allow to make presumptions that company like this can be taken as an example and correctly use their knowledge and experience.

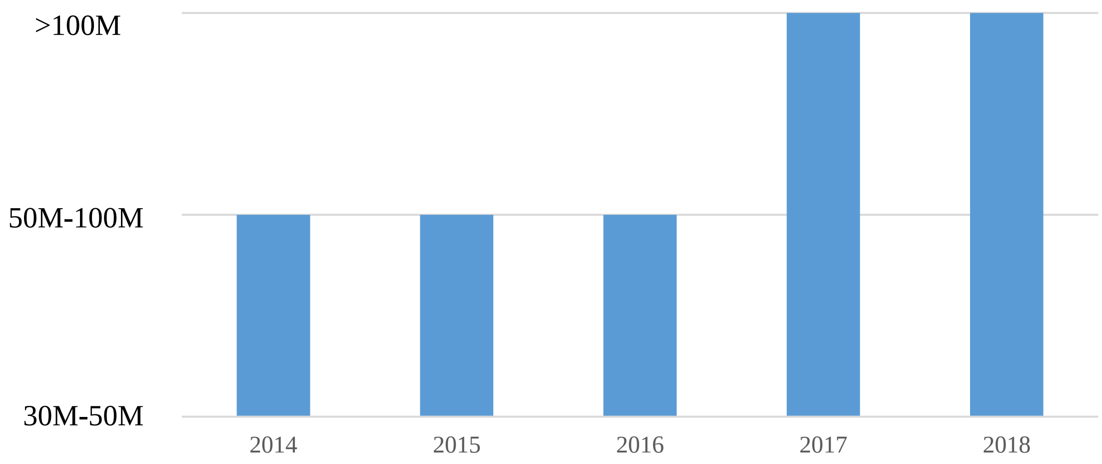


Fig. 9. SC "Freda" annual turnover [23]

2.2.1. Overview of Packaging line in SC "Freda"

The line consists of:

- Manual box folding area.
- Manual pick-and-place area for components.
- Automatic box closing area.
- Automatic unloading.

[3] MDF – Medium Density Fiberboard

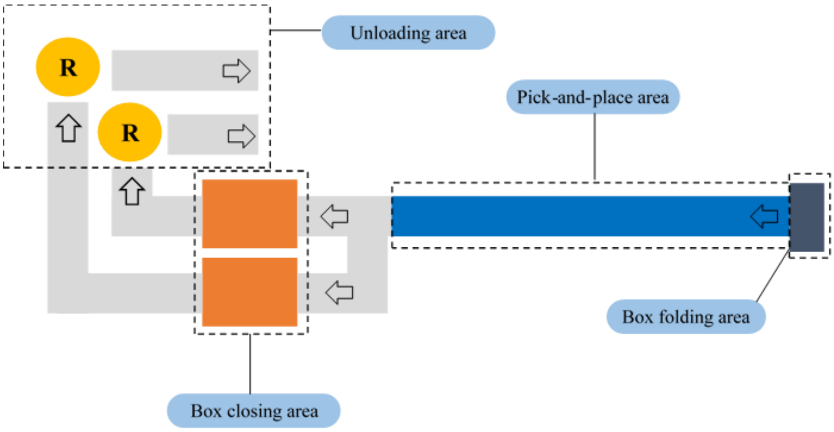


Fig. 10. Layout of SC "Freda" packaging line

Manual box folding area is located at the beginning of the line where workers manually assemble boxes from blanks. It contains up to four workers: two workers doing the assembly and two workers are preparing materials.

Fig. 11. Manual box folding area, SC "Freda" packaging line

Pick-and-place area is where all components are inserted into a box one by one in a set order. Boxes are being transported via belt conveyors and workers are laid out in both sides of the conveyor. Each of them is responsible for only one type of operation. As there are several types of articles, the number and layout of workers must be flexible to have fast change-over time between articles. The line is capable of fitting up to 54 workers by the conveyor.

While some employees are working with light materials such as polyester overlaps, fittings, cardboard fillings, etc., others are placing heavy parts – panels. In most cases articles consist of top, bottom and side panels with addition to fronts. By this, at least ten workers are needed per shift for panel placement. Heaviest panels can reach weight up to 12 kg. Because of this hard manual labour, there is a frequent rotation for workers that are responsible for placing the panels.

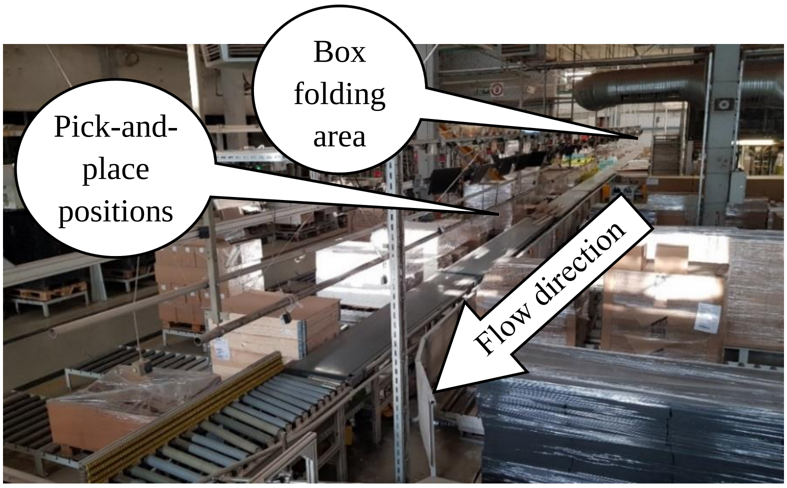


Fig. 12. Manual pick-and-place area, SC "Freda" packaging line

Box closing and unloading areas are combined and are automated. Box closing area contains two automatic box closing machines that can work in tandem mode or single-mode in case of malfunction. The output capacity is measured up to 9-10 boxes per minute, each.

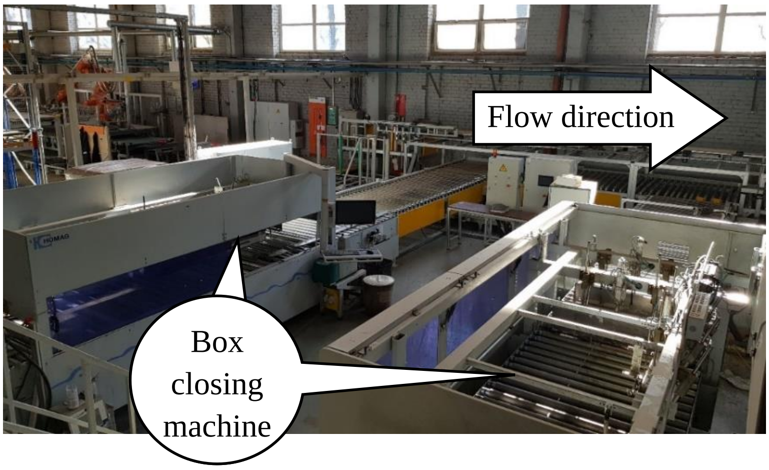


Fig. 13. Automatic box closing area, SC "Freda" packaging line

Once boxes are closed, they are transferred by conveyors to unloading area where robots place boxes on a pallet. Automatic box unloading area is equipped with two robots which use vacuum grippers for handling boxes. Each robot has a capacity up to 10 boxes/min. Boxes are stacked on pallets layer by layer until a complete pallet is finished. Afterwards, pallets are transferred to wrapping machines.

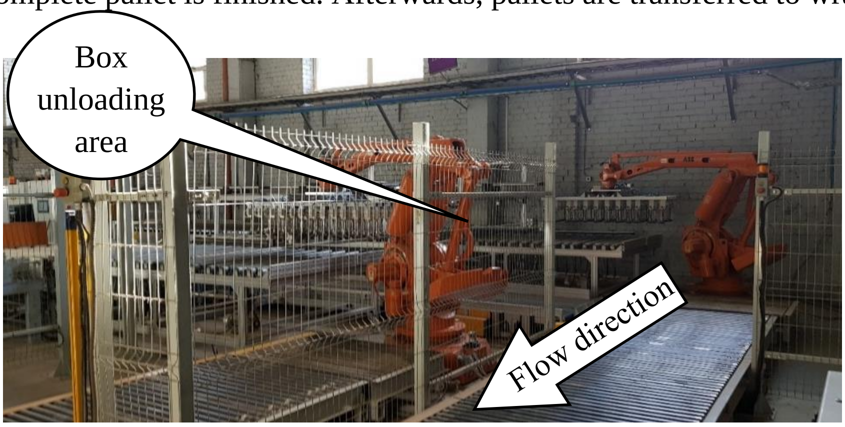


Fig. 14. Automatic box unloading area, SC "Freda" packaging line

The packaging line is capable of performing up to 18 boxes/min, because it is not possible to reach a higher performance rate with manual box folding. The production rate highly depends on a box length, as it is passing through box closing machines. In Table 1, production rates for some of the articles are given.

Table 1. Different packaging capacity rates according to article, SC "Freda"

Article	Dimensions (*length x width*), mm	Weight, kg	Capacity, boxes/min
Malm 2	500 x 400	17	18
Malm 3+3	1600 x 450	37	15
Alex 9	1200 x 420	36	16

For understanding the impact of how implemented automated system increased the production rate, manual and semi-automated packaging lines are compared. For equal comparison, the same article – Malm 2 is considered.

The packaging line modifications had been carried out in 4 steps:

1. Automatic box closing machine.
2. Automatic unloading.
3. Modification of automatic box closing machine and unloading system.
4. Additional box closing machine and additional robot for the automatic unloading.

The initial manual packaging line, with manual box folding, object inserting and box closing, had a capacity up to 4 boxes/min. Overall number of people by the line – 30 workers. At that case, the cause of low capacity was the box closing, as it took longest time – around 30 s/box. Because of it, an automatic box closing machine was added. This improvement led to increasing the capacity up to 7 boxes/min. Cost of machine – 110 000 Eur., number of workers – 35. Though the machine was capable of performing up to 10 boxes/min., it was not available because of the unloading. Automatic unloading with robot was added in that matter. This solution allowed to increase the capacity up to 10 boxes/min. Though the robot was capable of performing at a higher pace, it was the limit for the box closing machine. Cost – 150 000 Eur., workers – 40.

Due to increased demand, but with limited size of an investment, SC "Freda" took a decision of upgrading/modifying existing box closing machine and unloading system by adding NC axis. With a cost of 30 000 Eur., the capacity was increased to 12 boxes/min, and the number of workers in the packaging line grew to 50. The final step to currently existing packaging line was adding an additional box closing machine and additional robot to the unloading area. General investment size – 300 000 Eur. The packaging line's capacity was creased up to 18 boxes/min. As the production rate increased, additional workers were needed.

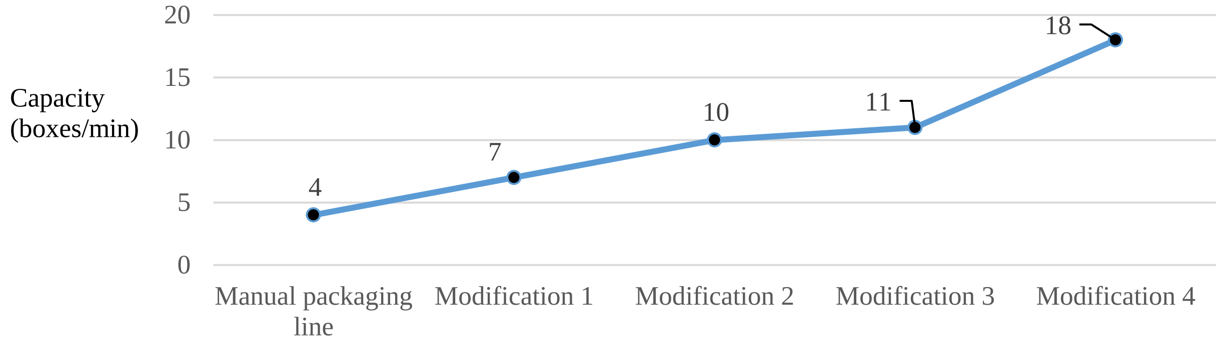


Fig. 15. Capacity variation according to packaging modifications, SC “Freda”

As shown in Figure 15, increase of the packaging line’s capacity, when compared to a manual one, is 350 %. However, the number of workers grew from 30 to 55, which is equivalent to 83 % increase. Table 2 shows the what kind of impact modifications had on capacity.

Table 2. Capacity increase in each modification

Stage	Capacity increase*, %
Modification 1	75 %
Modification 2	43 %
Modification 3	20 %
Modification 4	50 %

**Note – each modification is compared to a previous one.*

The overall investment size for modifications – 590 000 Eur. If considering the same worker wages – 1500 Eur./month for worker, 2000 Eur./month for operator (*Gross*), the salary expenses also grew – from 45 000 Eur. to 83 000 Eur., per shift, an increase of 84 %. Figure 16 illustrates the change of capacity and salary expenses between manual and semi-automated packaging lines when automated systems were implemented.

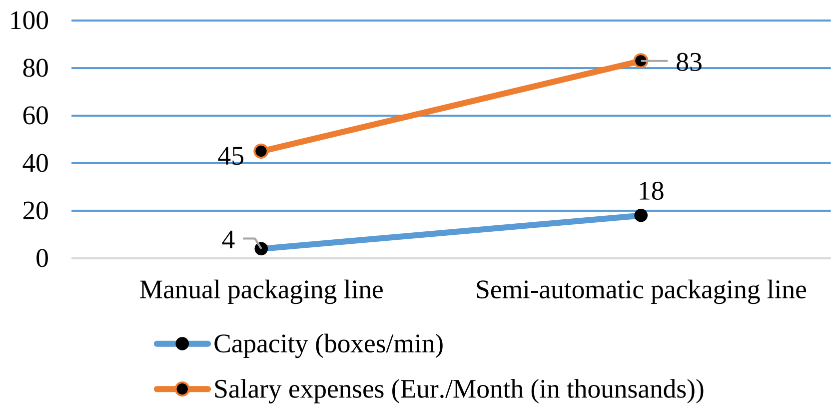


Fig. 16. Graphical illustration of capacity and salary expenses with manual and semi-automated packaging line, SC “Freda”

2.3. Conclusions of analysis on existing packaging lines

Though the companies are both in the furniture industry, the direction of them is entirely different. While JSC "Baltic Furniture Components" (*short name – BFC)* are mainly concentrated on single-part production with smaller batches, SC "Freda" (*short name – Freda)* is leading the way in the furniture mass production field. Due to this, adequate approaches are applied in these companies.

Table 3. Packaging lines' data comparison

Company	Investment, Eur.	Workers (*per shift*)	Capacity, boxes/min
JSC "Baltic Furniture Components"	200 000	3	6
SC "Freda"	590 000	55	18

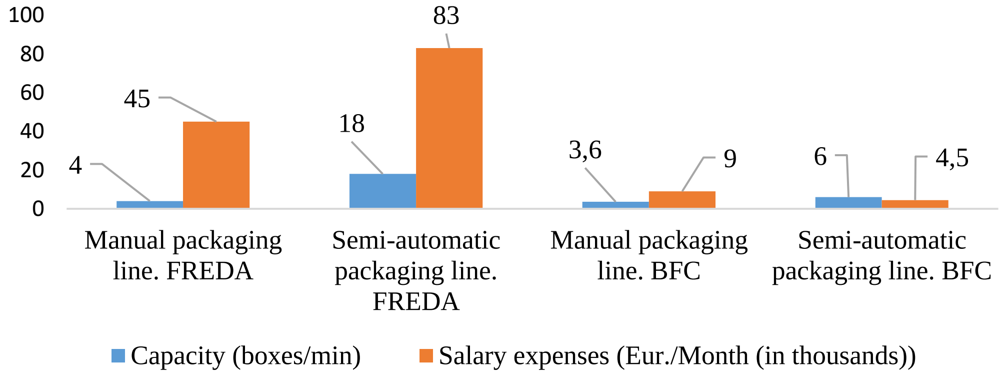


Fig. 17. Comparison of change of capacity and salary expenses

For calculating gains, companies are compared in one shift revenue and profit values. It allows to see what impact implementation of automated systems has made. For consideration, calculations will be done evaluating one 12-hour shift and profit margin of an average 7 %. An average selling price per article for BFC – 5,8 Eur., for Freda – 18,3 Eur. Also, for efficiency evaluation, OEE[4] is considered to be 75 %. With manual packaging line, BFC is capable of accumulating 11 275 Eur. of revenue, generating 789 Eur. profit. While with the automated line, it is increased by 66 %, reaching 18 792 Eur. revenue and 1 315 Eur. profit. In case of SC "Freda", semi-automated packaging line increased the revenue from 39 528 Eur. to 17 767 Eur. and 2 767 Eur. to 12 451 Eur. for-profit accordingly.

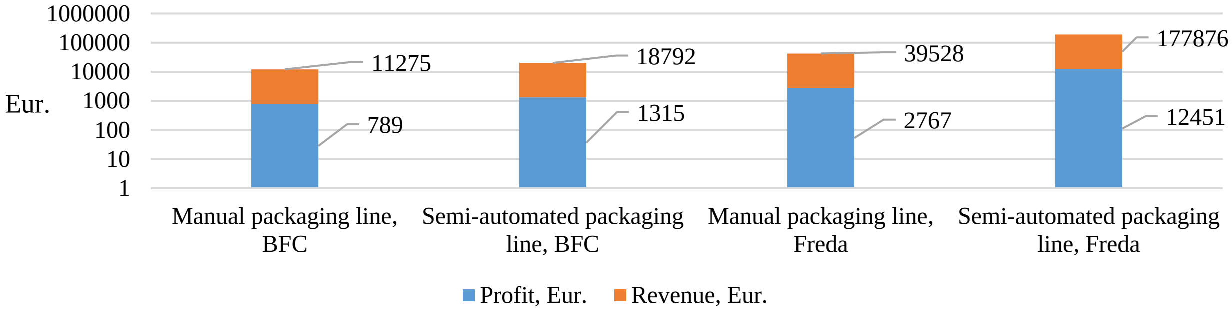


Fig. 18. Chart of revenue and profit comparison between manual and semi-automated packaging lines. *Note: chart is presented in logarithmic scale*

[4] OEE – Overall Equipment Effectiveness

An overview of existing packaging lines allows for a better understanding of what kind of solutions are already implemented and works in real-world situations and which areas can still be improved in the future.

The analysis of existing packaging lines considered two furniture companies: JSC “Baltic Furniture Components” and SC “Freda”. It showed that companies took a decision of investment for applying automated systems for their packaging lines. JSC “Baltic Furniture Components” implemented an automated machine which replaced manual labour for box folding, panel insertion and box closing. SC “Freda” installed two automated box closing machines and designed an automated outfeed system to fulfil their requirements. These decisions provided an increase to capacity, which allowed to reach higher profits. Based on this data, box folding machine, box closing machine and an automated box unloading will be used in designing the packaging line. However, the analysis showed that panel insertion is another field that can be improved.

3. Design of packaging line

The design stage of packaging line contains an overview of conditions and requirements which are raised for this kind of line, a concept of how the line will be fulfilled and applied, what machines are selected and what automated systems are designed and implemented.

Generally, basic packaging line can be divided into several areas:

1. **Box erecting area** – an area where boxes are assembled into shape from blanks.
2. **Pick-and-place area** – an area where workers put relevant items into boxes.
3. **Box closing area** – an area where filled-up boxes are closed and sealed.
4. **Unloading area** – an area where boxes are collected and placed on pallets.

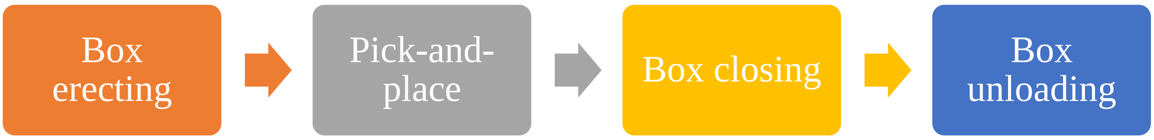


Fig. 19. Packaging line flow

This basic concept is used for understanding the flow and procedure of the packaging line. In addition to this, it is the basis for what the further automated systems will be applied on. Design stage contains the solutions that were overviewed in the analysis stage, calculations which are based on the initial data and requirements and will consist of the following steps:

1. Analysis of packaging article. An order in what the article must be arranged is studied with technical details.
2. Overview of requirements and conditions.
3. Concept of the line is made in order to set up basics for further design of exact machines and systems.
4. Selection of a box folding machine.
5. Selection of a conveyor and design of a robot cell.
6. Selection of a box closing machine.
7. Design of an automated unloading system.
8. Economic calculations.

3.1. Analysis of packaging article

For designing the line, information of articles’ type and arrangment is needed. For examination, basic article was chosen, on which other future articles will be based on.

The article consists of main parts such as panels, drawers, fittings and additional materials such as fillings and foam films. All of them are described and set in order, according to the article in Table 4 and Table 5. Complete article arrangement is presented in Appendix 2.

Table 4. List of packaging materials

Position	Description	Size, mm
A	Main carton box	729 x 453 x 88
B	Carton box for fittings	450 x 80 x 75
C	Honeycomb filling	450 x 85 x 12
D	Honeycomb filling	450 x 180 x 18
E	Honeycomb filling	178 x 62 x 68
F	Honeycomb filling	280 x 55 x 16
G	Honeycomb filling	347 x 88 x 34
H	Carton filling	370 x 170 x 7
I	Honeycomb filling	410 x 30 x 12
J	Foam film	455 x 455 x 0.6
K	Foam film	680 x 450 x 0.6

Table 5. Article assembly steps

Step	Description
1	Side panel, right side. Fillings C, D, E
2	Side panel, left side
3	Drawer side (x4)
4	Drawer front (x2)
5	Back panel
6	Back wall (x2)
7	Bottom of drawer (x2)
8	Assembly instructions
9	Foam film

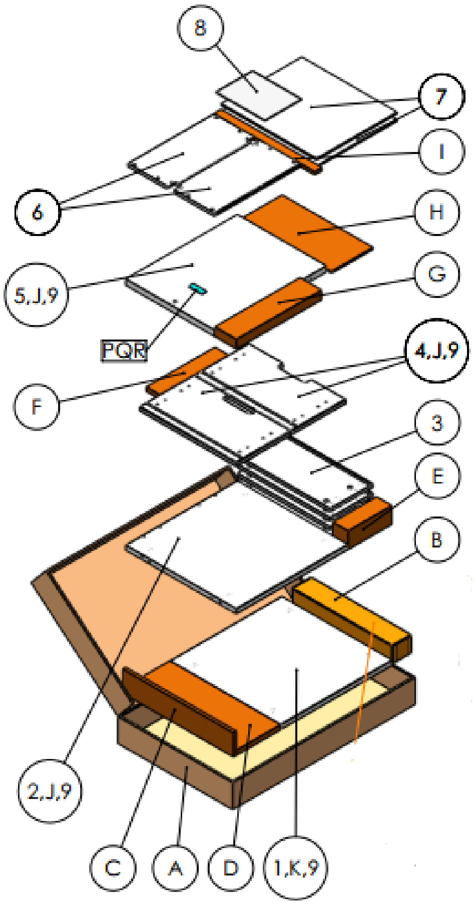


Fig. 20. Exploded article view

From the article description, the arrangement of positions can be determined - when and which item must be put inside a box. Though it is only one article which is being examined, the overall structure maintains the same for other articles. Differences can be seen in size, quantities. However, it is essential to evaluate some flexibility as a possibility of changes in the future are likely.

Boxes must be arranged in an order on a pallet which is provided in the packaging drawing. They are placed one by each other, on the lengthwise side stacking ten layers, according to this article. Note that each box layer is separated with cardboard overlap 800 x 650 x 3 mm. The set order is shown in Figure 21.

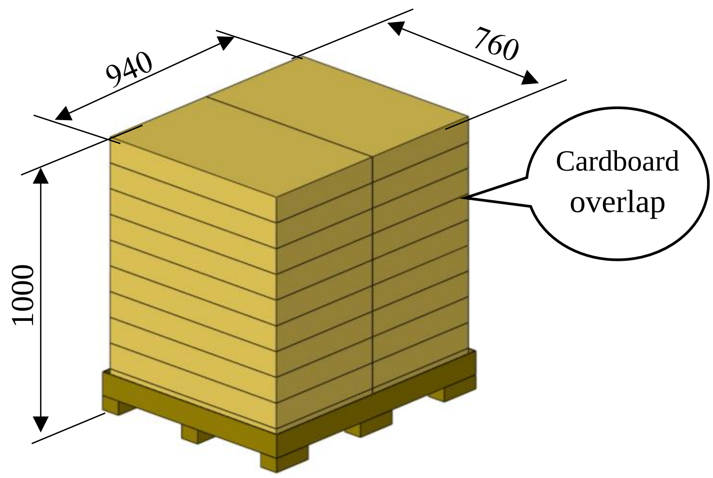


Fig. 21. Pallet visualisation with dimensions

According to the set-up orders and placement, the following design on packaging line will consider work position arrangement and robot cell placement by the conveyor.

3.2. Overview of requirements and conditions

For the design stage, it is crucial to fully analyse the requirements and needs. Missed information could lead to re-doing the work, or additional costs in later stages. The requirements and conditions that need to followed and fulfilled are:

- Capacity – 23 boxes/min.
- Maximum 2 operators for line.
- Payback must be reached within a 5-year period.
- Line must fit in dedicated space (*Appendix 1*).
- Automated systems must reduce the number of workers when compared to manual packaging line.

When it comes to capacity requirement for the packaging line, the decision of setting up the line has to consider not only the technological possibilities of machines, which are available in the market, but also the physical options of workers who would perform by the line.

As the limit for inserting objects into boxes can be considered to be up to 12 pcs/min, the amount of people to fulfil the requirement would have to be double, and the line would have to be the double-length. The limitation of the number of operators compels to consider position and how the machines will be operated, serviced by supplying materials and making adjustments. As of being a single and complicated line, the need for constant monitoring and analysing the ongoing status is crucial for efficient and optimised work. Centralised work position and control panel would offer the operators a convenient monitoring and quick decision making.

The requirement of payback period must be reached within 5-years, acts as a condition for searching and analysing both technical possibilities in which area, the money can be saved and the overall line efficiency – how to gain maximum output with minimum effort and input. Savings can be done in the design stage by selecting different materials, different suppliers also in working efficiency by using the same solutions or ideas.

As of dedicated space – the line must fit in the area and fulfil other conditions as well. The building was designed in such a way that the final products would go directly to the warehouse area, this solution allows to reduce time and travelling cost. Final product – boxes would go through a special gate through the firewall and from there would be stored or dispatched in different conditions. The sketch of the hall is presented in Figure 22. The dedicated space can be divided into two parts: part one is the main area in the general production hall and part two, which is located in the warehouse. Meanwhile, these two areas are connected with a passageway through the gate in the firewall.

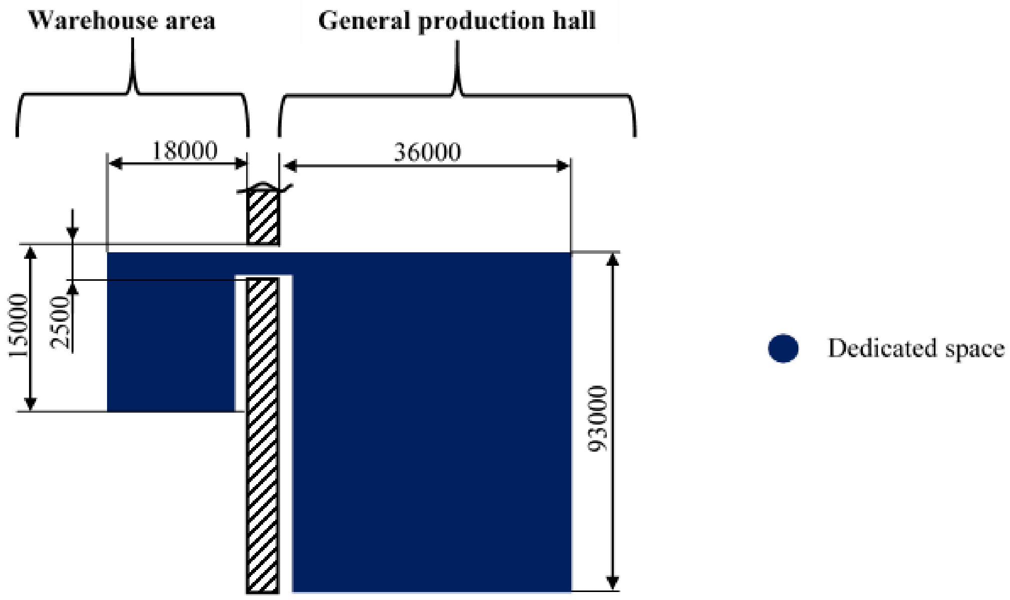


Fig. 22. Sketch of designated hall for packaging line
Note: sketch is not in scale

Evaluation of automation level can be determined through a comparison – how many people were reduced because of the implemented system. Also, this number is used in payback calculations, as it has a direct impact to the payback duration. However, it is important to evaluate that the automated system has other points which must be thought off.

For example, automated systems require maintenance with higher technical knowledge and qualification once compared to regular machinery. Additionally, annual maintenance procedures, malfunctions, spare parts are points that should be considered due to costs that were ongoing with workers. Also, evaluation of how automated systems could be bypassed because of malfunction or other reasons would allow flexibility, as in some cases, the complete production flow could be stopped due to one automated system.

3.3. Concept of packaging line

The concept of packaging line is based on analysis of real-world packaging lines which were analysed and requirements which have to be met. Different methodologies and logic can be applied when considering the concept.

The concept can be divided into these areas:

1. Box folding area
2. Conveyor with designated pick-and-place positions for object insertion.
3. Box closing area.
4. Box unloading area.

Each area is dedicated for different operation, for which different systems are used. Table 6 explains what kind and what system is implemented in each area.

Table 6. Concept of solutions for packaging line

Box erecting		Inserting objects in box		Box closing		Unloading	
Type	*Done by*	*Type*	*Done by*	*Type*	*Done by*	*Type*	*Done by*
Automated	Machine	Semi-automated	Human + robots	Automated	Machine	Automated	Robots

The selection of systems is based according to calculations from JSC "Baltic Furniture Components" and SC "Freda". Automatic box closing machine allowed to increase the capacity by 75 % and automatic box unloading by an additional 43 %, in SC "Freda" case. Based on these numbers, we can see that automatic systems made a big improvement in the production rate.

As the intention of the company was to provide finished products directly to the warehouse area, the designated place for the packaging line is in U shape and crossing the firewall, as shown in Figure 23. This is done due to regulations of fire safety and efficient production flow. The general area, had to be divided into place for machinery and place for a buffer area, as it would be responsible for material and article supply for the packaging line.

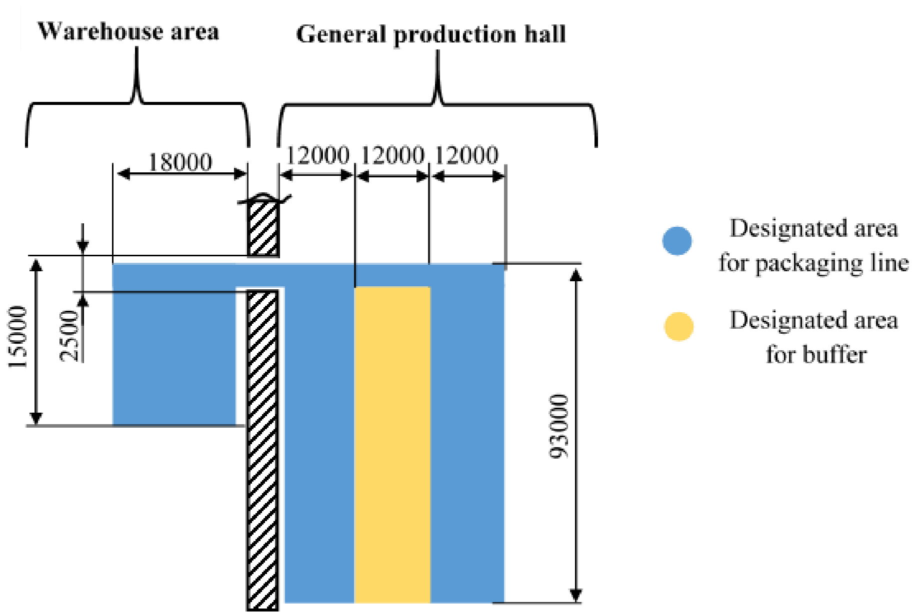


Fig. 23. Sketch of designated hall for line *Note: sketch is not in scale*

Due to this and because of high capacity requirements, as

there are no standard machines for these production rates, the decision was taken to create two parallel packaging lines. Unloading area would be the joining point where two flows meet each other. The decision of making two parallel packaging lines means higher investment size, as a double number of machines for both box folding and box closing is needed. However, this provides additional flexibility to the system.

The general concept of packaging flow is shown in Figure 24. The flow starts from box folding machines. Afterwards, boxes are being transported on a conveyor where workers and robots are doing the pick-and-place task in order to fill the article. Once boxes are completed, they are closed with automatic box closing machines.

Closed boxes are moved via transporters to sorting and unloading area. In there, boxes are stacked on pallets with the use of robots with vacuum grippers. The complete control and monitoring is done via control panel and cameras, which are controlled by operators.

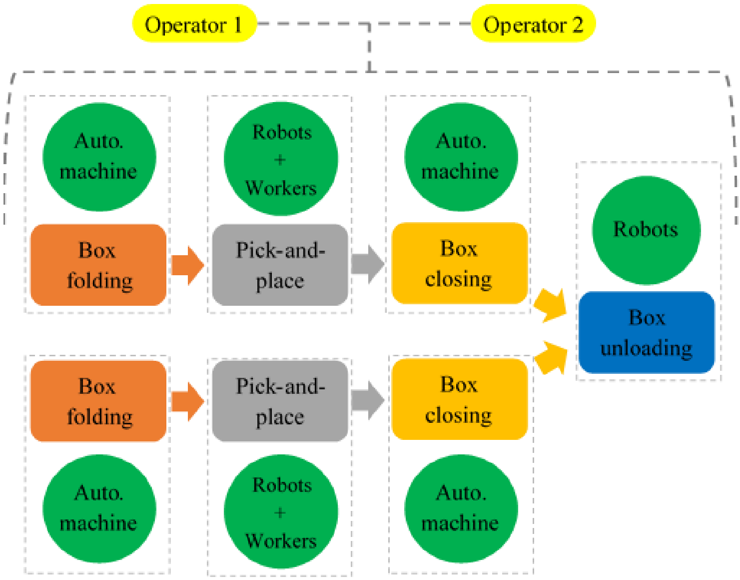


Fig. 24. Concept structure of packaging line

According to the concept flow, the initial sketch layout is done, Figure 25. The machines and automated systems are positioned in a rough place, as actual dimensions are not yet known. In the figure, no. 1 is shown the start of complete line – box folding machines. Next, no. 2 follows conveyor, where the pick-and-place task is done, in relation to this, no. 3 illustrates automatic robot cells, which will be responsible for panel insertion. no. 4 shows box closing machines. After this, the transportation system to the unloading area is marked no. 5., while the unloading system – no. 6.

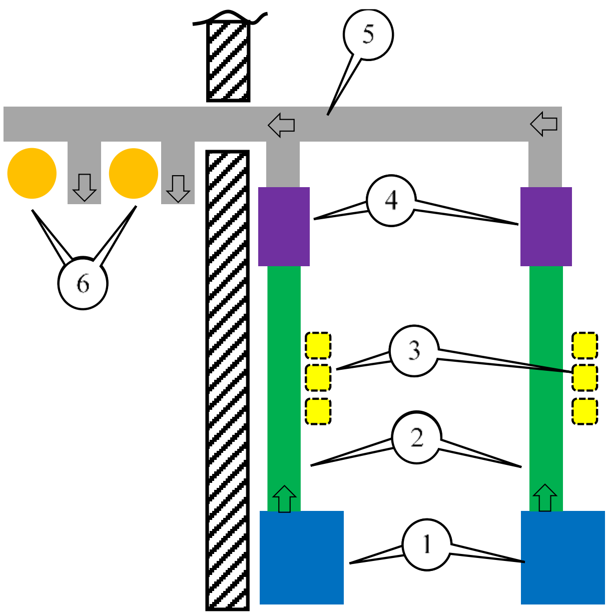


Fig. 25. Sketch layout of packaging line. *Note: sketch is not in scale*

3.4. Box folding

Box folding is a task of forming a box from blanks to a shape by folding sides and fronts and fixing them together whether with clips or glue. The boxes are used for packaging various objects and materials, while in this case, it is furniture. The boxes itself are basically grouped into 3 common types. Folding cartons - most met type of boxes as it is mostly used for packaging small and simple objects, also it is widely used in the food industry. Rigid boxes are sturdy and do not collapse easily under pressure, though costs of this type are quite high, it is used for high-end products or fragile products which needs additional packaging protection. Corrugated boxes are widely used in industrial packaging due to low price and simple folding. This type of boxes usually has three layers – wavy or fluted layer sandwiched between two outer layers. The corrugated boxes are those which is used in furniture packaging.

As the company is an IKEA supplier, it is needed to follow certain regulations which also covers, in this case, particular standards. One of the requirements is to use FEFCO (*The European Federation of Corrugated Board Manufacturers*) standard corrugated boxes – 0410, as shown in Figure 26.

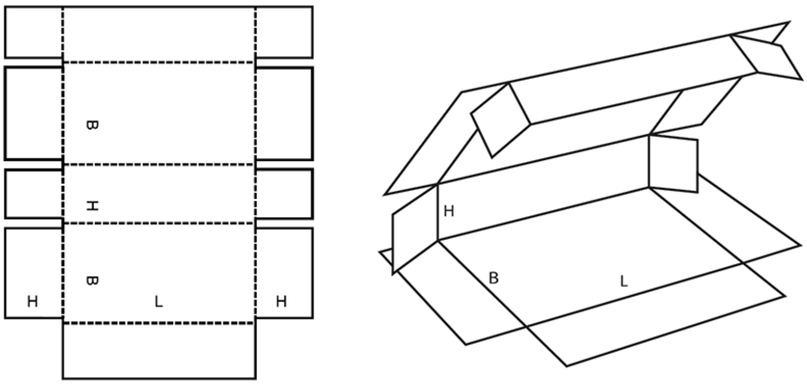


Fig. 26. FEFCO 0410 box sketch [24]

Considering the packaging instruction (*Appendix 2*) and evaluating flexibility, following sizes, which are shown in Table 7, are taken as standard, which needs to be fulfilled.

Table 7. FEFCO 0410 box dimensions

	Length, mm	**Width, mm**	**Height, mm**	**Wall thickness, mm**
Minimum *(at least)*	400	400	40	3
Maximum *(at least)*	1600	600	150	4

The decision of selecting an existing machine and not to design a new one is based on several factors: the price of a designed machine would be higher, as standard machines are sold in higher numbers, which reduces the production cost. The other point is the know-how factor as this is a specific task that needs to be carried out with many considerations, such as cardboard friction, cardboard vacuum level and other.

3.4.1. Analasys of Magnys FM410

This automatic box folding machine from JSC “Magnys” (*Italy*) was explicitly designed to handle box formats FEFCO 410. On the first workstation, the head end flaps are folded and glued with hot melt glue. On the second workstation, the back ends are folded and glued with hot melt glue, thus forming the bottom tray of the box.

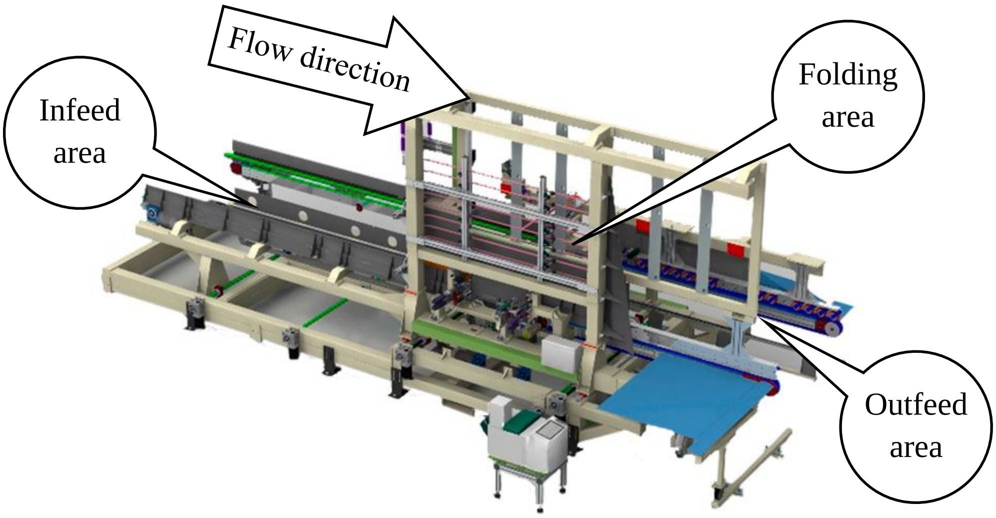


Fig. 27. Magnys FM410 box folding machine [25]

According to the product description, which is stated in Table 8, the machine is fulfilling the requirements of sizes as it falls within the needed interval.

Table 8. Magnys FM410 product description

	Length, mm	Width, mm	Height, mm	Wall thickness, mm
Minimum	400	220	30	2
Maximum	2500	1200	250	4

The machine is capable of performing up to 10,4 boxes/min with boxes which has a length up to 1300 mm. Above this, the performance drops by 25 %, to 8,5 boxes/min.

Table 9. Magnys FM410 capacity

Length, mm	Capacity, boxes/min
400 - 1300	10,4
1301 – 2500	8,5

Though the machine offers automatic box folding function, the material, box blanks, must be inserted manually. This leads to an increased number of employees who must operate the machine. In addition to this, a time delay occurs while changing the material’s pallet. It is considered that the pallet consists of 300 pieces of blanks, every 29 min a change-over of pallet would lead to complete line stop for 2-3 min. When calculating this into 12-hour shift, it reduces the OEE additionally by 5,5 %. In order to reduce this downtime, an automatic loading system must be implemented. With automated infeed system, the set-up time is reduced from 15 to 10 min.

The manufacturer claims that the machine offers availability of 75 % of availability. Machine availability is a percentage of time that production equipment is available for use, divided by the maximum time it would be available if there were no downtime for repair or unplanned maintenance. The total machine price, including the automated feeding system, is 320 000 Eur.

In order to have a clear comparison between machines, crucial parameters such as, capacity, price, availability, set-up time are evaluated. For visualising the expressed parameters, a radar chart is used. – Figure 28.

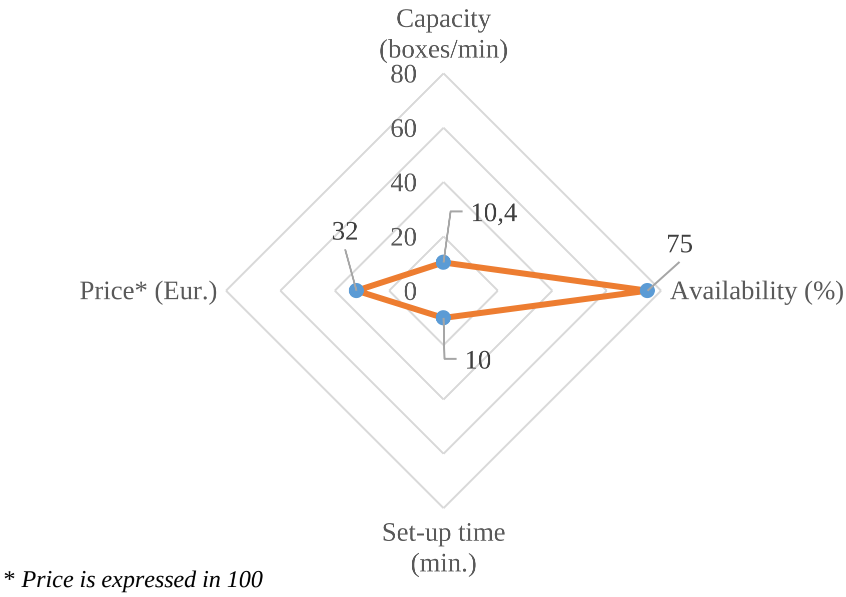


Fig. 28. Magnys FM410 parameter radar chart

Additional parameter which is compared among machines is the ratio between capacity and price. This ratio allows to compare machines on equal state, as it indicates the true value of a machine. For Magnys FM410 price/capacity ratio is 30,77 (*thousands*).

3.4.2. Homag Paqteq F-200

Box folding machine is designed and manufactured by „Homag Automation GmbH“ (*Germany*). Punched and pre-stamped (grooved) cardboards are provided in an aligned way before the folding station. The provision is executed according to the chosen feeding variant. The respective cardboard sheet is fixed by means of vacuum type suction elements and drawn into the folding station. The longitudinal flap and the lid are set upright during the loading operation. Subsequently, the two cross sides of the cardboard box are folded and glued in two steps. Afterwards, the finished cardboard box is transferred to a conveying element and the following packaging line with the lid being upright. The cardboard-box folding machine is adjusted to other cardboard box sizes in a motorised way by means of the control.

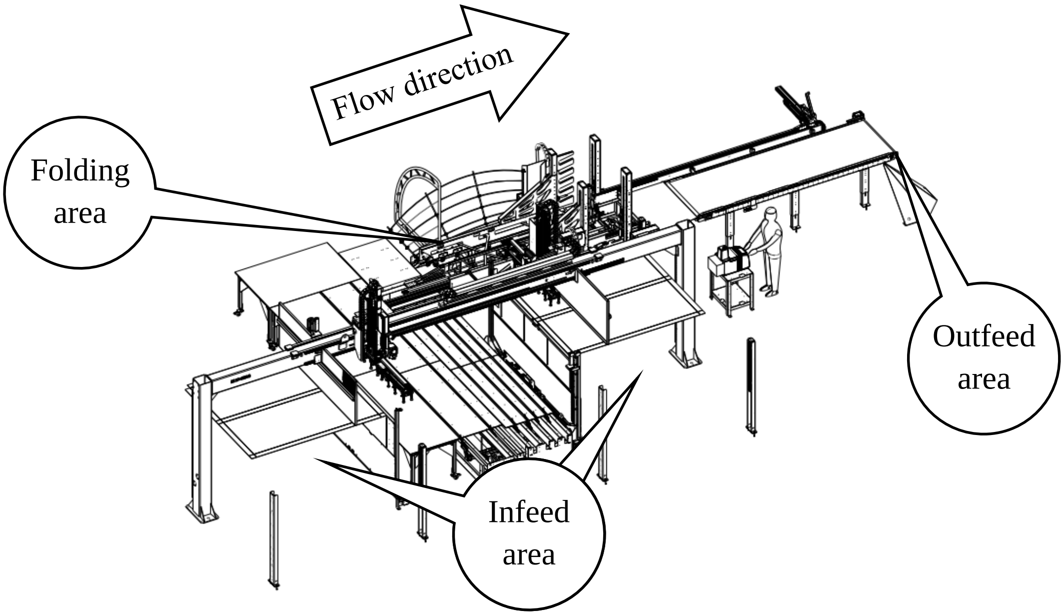


Fig. 29. Homag Paqteq F-200 [26]

As the machine is designed to have two separate infeed areas, this allows for uninterrupted flow of materials. While the machine is working from one infeed area, the other one can be set and prepared without stopping the machine, meaning that the line can work without interruption. According to the product description (*Table 10*), the machine fits in the needed product dimension interval.

Table 10. Homag Paqteq F-200 product description

	Length, mm	**Width, mm**	**Height, mm**	**Wall thickness, mm**
Minimum	380	200	32	2
Maximum	2500	1100	250	4

In Table 11, the capacity rates are expressed in relation to product length. As it states, increased box length reduces the capacity accordingly. However, the maximum 11,8 boxes/min output satisfies the requirements.

Table 11. Homag Paqteq F-200 capacity

Length, mm	**Width, mm**	**Capacity, boxes/min**
380-1000	<=600	11,8
1001-2500	<=600	10,2

Due to double infeed area, the machine dimensions are higher when compared to Magnys FM410, though they still fall in the boundaries.

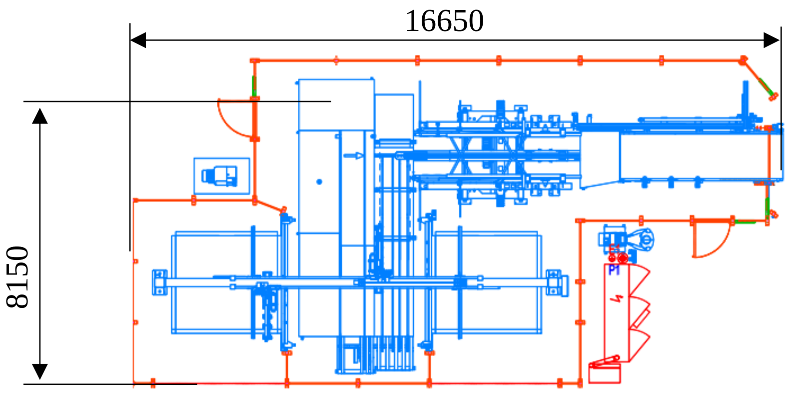


Fig. 30. Sketch of Homag Paqteq F-200 [26]

As the machine is fully automatic, the set-up time is reduced to a minimum. This is especially important when the line is in transition mode between articles, in this case, the only thing that the operator needs to consider is the program selection in the Human-Machine-Interface (HMI).

The machine offers 85 % of availability, which when compared to Magnys is 10 % higher.
With configuration for 11,8 boxes/min capacity, the price of Homag Paqteq F-200 is 385 000 Eur.

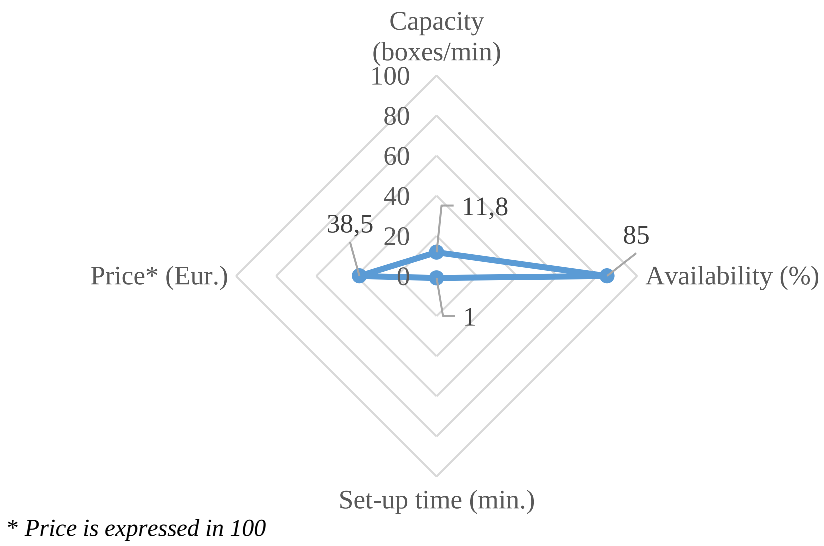
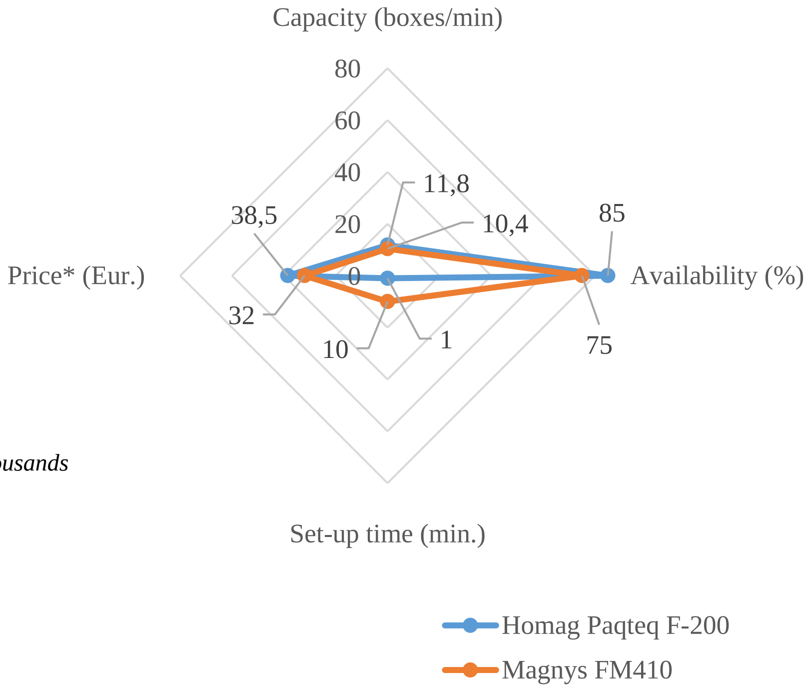


Fig. 31. Homag Paqteq F-200 parameter radar chart

If evaluating the price/capacity ratio, Homag Paqteq F-200 machine has a ratio of 32,63 (*thousands*).

3.4.3. Conclusion of box folding machine

Analysis of different box folding machines provides data and characteristic which can be compared and evaluated. This is important, as comparison of the same parameters allows to notice pros and cons in the same fields and ground the selection decision. Radar chart (*Fig. 32*) illustrates the parameters which are compared amongst the machines – capacity, price, availability and set-up time. According to it, Homag Paqteq F-200 has an advantage over Magnys FM410 in capacity (higher 13,4%), availability (higher 10%), set-up time (lower 90%). However, the price of Homag machine is also higher by 20 %.



** Price is expressed in 100 thousands*

Note:
Capacity - higher is better;
Price - lower is better;
Availability - higher is better;
Set-up time - lower is better;

Fig. 32. Machine parameter comparison between Homag Paqteq F-200 and Magnys FM410

Additional parameter that is taken for consideration is price/capacity ratio. Magnys FM410 has a better price/capacity ratio by 6 %.

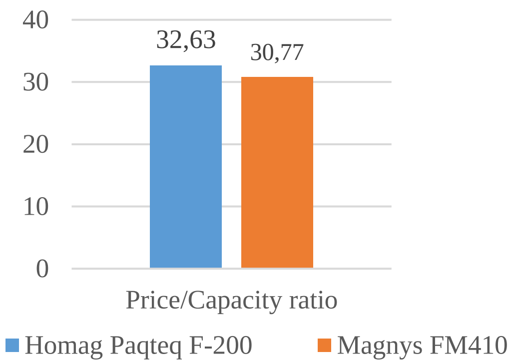


Fig. 33. Price/capacity ratio comparison between Homag Paqteq F-200 and Magnys FM410

Though Magnys FM410 offers better price/capacity ratio, the longer set-up times and smaller availability makes the Homag Paqteq F-200 machine a better long-term choice.

3.5. Box closing

Box closing is a task that relates to glueing and closing box flaps. As in this matter, FEFCO 0410 box type is considered, two edges and one lengthwise flaps are needed to be closed. To add on, because the box closing machines are being placed in a line, the same requirements must be met as for box folding machine.

3.5.1. Magnys CM410s

The machine was specifically designed to close box formats FEFCO 0410 automatically. The longitudinal flap and the two transversal flaps of the lid are glued by means of hot melt glue. As the machine is designed to work in tandem with Magnys FM410, the technical product description is the same.

Table 12. Magnys CM410s product description

	Length, mm	Width, mm	Height, mm	Wall thickness, mm	Package weight, kg
Minimum	400	200	30	2	-
Maximum	2500	1200	250	4	55

The capacity, which Magnys CM410s offers, is also related to product length. With 400-1300 mm length boxes, the machine is capable of performing up to 10,8 boxes/min, technical documentation states. Length above 1300 mm reduces the capacity by 16 %.

Table 13. Magnys CM410s capacity

Length, mm	Capacity, boxes/min
400 - 1300	10,8
1301 – 2500	9

For box closing machines, same parameters – price, capacity, availability and set-up time are analysed and compared. The manufacturer declares the same 75 % of availability for this machine. However, as the machine is fully automated, the set-up time is reduced to a minimum – 1 min. This means that the operator must only select according program from the HMI and the machine sets-up everything by itself. Machine price – 115 000 Eur. Parameters are expressed visually in radar chart, Figure 34.

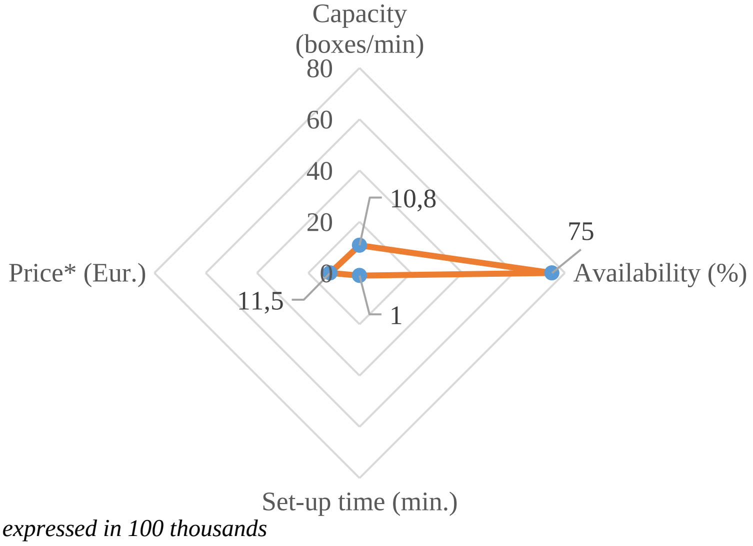


Fig. 34. Magnys CM410s parameter radar chart

If considering the price/capacity ratio, the machine price reaches 115 00 Eur., while the maximum output is 10,8 boxes/min. This means Magnys CM410s has a price/capacity ratio of 10,65 (*thousands).*

3.5.2. Homag Paqteq S-200

Incoming packages are taken and accelerated by the preceded transport distance. As the Same time, the vertical cover is folded. During the through feed 1 or 2 lines Hot Melt are being applied on the longitudinal side of the carton, depending on the height of the carton. The packages are positioned and stopped over the front edge. The Hot Melt is applied to the front transversal side by means of a mobile nozzle. Then both cover flaps are glued from above to the carton by pressing elements. After a short pressing time, the packages are being forwarded to the next segment and glued at the rear transversal side according to the same principle.

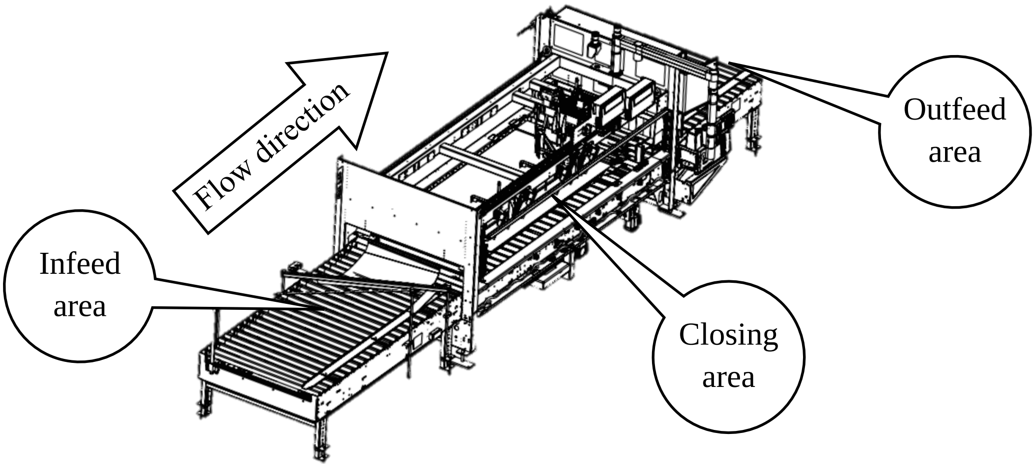


Fig. 35. Homag Paqteq S-200 [26]

The machine is capable of coping with products which parameters are stated in Table 14. Additional parameter which needs to be considered is package-box weight. Boxes which are above 80 kg. are not suitable for the machine anymore.

Table 14. Homag Paqteq S-200 product description

	Length, mm	Width, mm	Height, mm	Wall thickness, mm	Package weight, kg
Minimum	400	180	22	1,5	-
Maximum	2500	1100	250	3	80

Homag Paqteq S-200 offers different output performance which is related to box length. The difference between box folding machine is that box width also impacts the capacity. From Table 15, we can see that the highest output is when the box length is under 1000 mm and the width less than 600 mm. With these parameters, the machine is capable of performing up to 11,9 boxes/min. With length above 2000 mm the machine has the least capacity which reaches 9,5 boxes/min.

In addition to this, the machine is capable of working in batch-size-one mode, which allows to have every box in different size. Machine automatically detects the incoming box and calculates its dimension for fast, automatic adjustment. However, this feature reduces the output performance by 10-15 %.

Table 15. Homag Paqteq S-200 capacity

Length, mm	Width, mm	Capacity, boxes/min
380-1000	<=600	11,9
1001-1500	<=600	11,1
1501-2000	<=600	10,5
1001-1900	<=410	11,4
2001-2500	<=600	9,5

As the machine is fully automated, the set-up time is declared up to 1 min. In addition to this, Homag declares the same availability for box closing machine – 85 %. This allows to use the machine more efficiently over shift. With the declared parameters, the machine price is 124 000 Eur. These parameters are displayed in the radar chart, Figure 36.

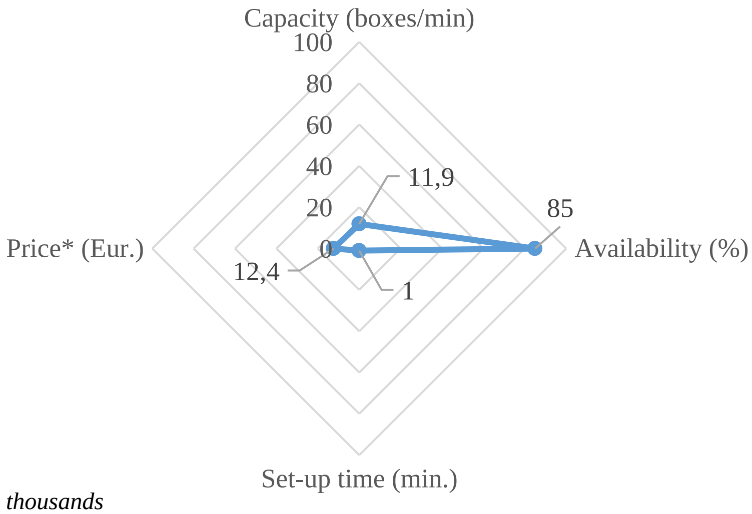


Fig. 36. Homag Paqteq S-200 radar chart

Because of lower price and similar output, the price/capacity ratio is better, when compared to box folding machine (*Homag Paqteq F-200*). With 124 000 Eur. Price and 11,9 box/min capacity, the ratio is 10,42 (*thousands*).

3.5.3. Conclusion of box closing machine selection

For box closing machine selection, analysed parameters of both machines – Magnys CM410s and Homag Paqteq S-200, are expressed in the radar chart, Figure 37. From machine performance output, it can be seen that Homag has a higher capacity by 10 %. With addition to availability, which is 85 % against 75 %, the total outcome in one shift can be expressed in 7280 boxes with Homag Paqteq S-200 and 5832 boxes with Magnys CM410s. The entire outcome with Homag is almost 25 % higher when compared to Magnys. This number allows to accept a higher price for Homag Paqteq S-200, that is 8 % larger than Magnys CM410s. Regarding the set-up time, box machines offer fully automatic adjustments for article change-over.

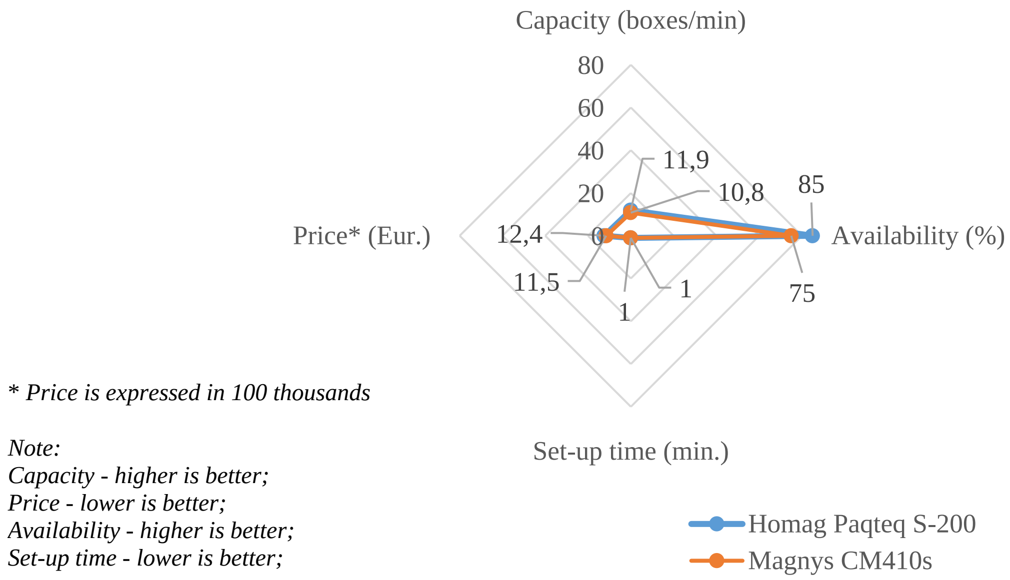


Fig. 37. Machine parameter comparison between Homag Paqteq S-200 and Magnys CM410s

In addition to earlier mentioned parameters, the selection can also be based on price/capacity ratio, which Homag machine provides less by 2,2 %.

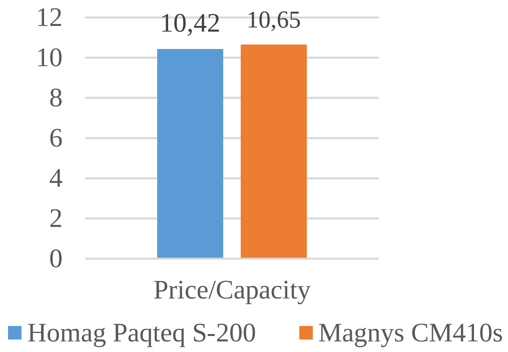


Fig. 38. Price/capacity ratio comparison between Homag Paqteq S-200 and Magnys CM410s

The collected and analysed data is used to ground the decision of selecting Homag Paqteq S-200 for box closing application.

3.6. Conveyor – pick-and-place

With selected machines, both for box folding and box closing tasks, the next step consists of designing the workspaces for article insertion by the conveyor. In addition to this, robot cells for panel insertion will also be covered.

With placed machines, the residual space left for conveyor is 59000±1000 mm., as shown in the sketch, Figure 39. According to this length, the conveyor itself must be selected, and adequate workplaces for workers must be laid-out with cooperation with robot cells.

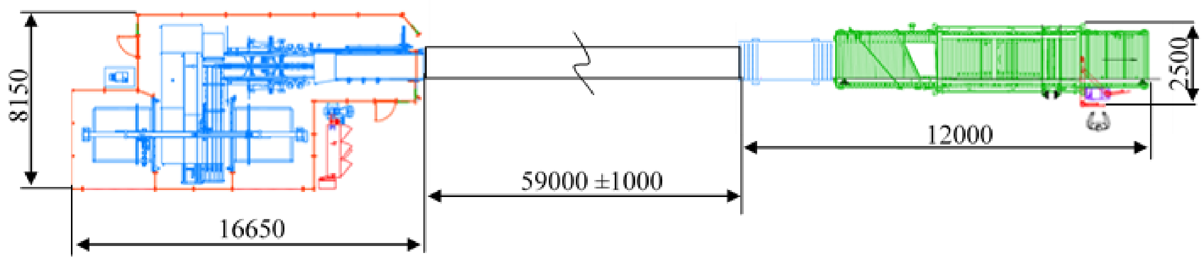


Fig. 39. Sketch layout of packaging line

3.6.1. Conveyor selection

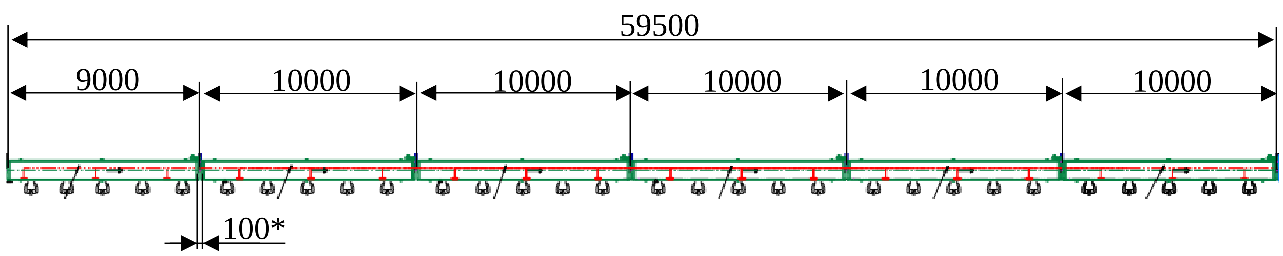
For conveyor selection, several aspects must be considered and evaluated. It is vital not only to contemplate the technical parameters of the conveyor but also the ergonomic part, as the physical work for personnel might have an impact of the overall packaging line's performance output.

According to ISO standard 6385:2016, the convenient working height for a worker, while work is being done in standing position, is between 900 to 1200 mm. [27]. Higher heights of conveyors or other working places are needed for greater precision tasks, such as microelectronic assembly, etc. Based on this, and the selected machines, the working height is set to 900 mm. Considering technical parameters, speed and package weight needs to be evaluated. In order to maintain a constant box closing machine's output with 500 mm gap between boxes, conveyors' speed must reach 30 m/min with box weight up to 80 kg.

The decision was taken to choose a standard solution from Homag, due to several benefits. Standard solution cost less when compared to newly designed, as there are no special requirements. In addition to this, having a single manufacturer line provides technical possibilities, such as line control and monitoring, tele-service. The conveyor line is made of 6 conveyors, with the same technical characteristic, shown in Table 16.

Table 16. Conveyor technical specification

Length, mm	**Width, mm**	**Belt width, mm**	**Height, mm**	**Electrical power, kW**	**Linear speed, m/min**	**Price *(per set)*, Eur.**
9000-10000	900	800	900	0,75	10-35	55000



**- 100 mm. gap is between all conveyors*

Fig. 40. Layout of packaging line 's conveyor

By the conveyor layout, there is a possibility of fitting up to 36 workers by the line. The worker displacement is related to article assembly and can vary according to it. Each worker position is equipped with a lifting platform equipped with conveyor, where adequate article parts are placed for insertion.

The lifting platform is capable of lifting weight up to 1500 kg, and the roller conveyor is designed in a way to store two 1-meter length euro pallets or one protection board (*3000x1000 mm.*), depending on the needs.

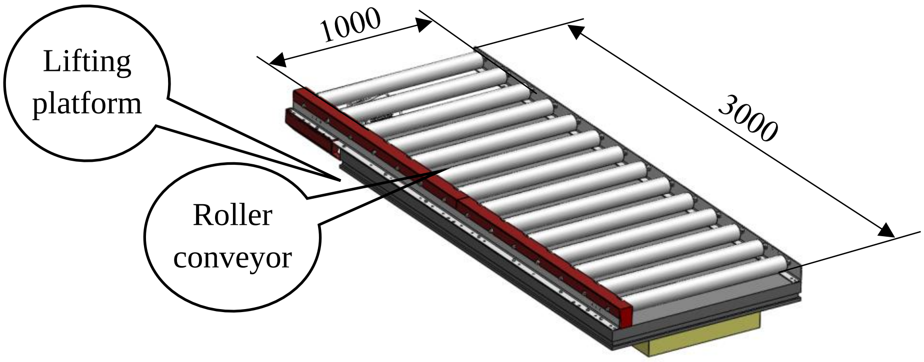


Fig. 41. Lifting platform with roller tracks

The lifting platform provides ergonomic workplace, as it raises up the stack to a desired height, so that the workers would not need to bend, as the stack is getting smaller. Technical specification of the lifting platform is provided in Table 17.

Table 17. Laweco lifting platform technical specifications

Manufacturer	**Dimensions (*length x width x height*), *mm***	**Type**	**Maximum lifting height, mm**	**Maximum lifting weight, kg**
Laweco	2500 x 900 x 200	Hydraulic	1050	1550

3.6.2. Robot cell

One of the goals of this work is to implement an automated system for panel insertion into boxes. As this is the most energy-consuming task due to heavier weights, when compared to other elements and monotonous rhythm.

For fulfilling this goal, a flexible robot cell was designed, which would replace workers for panel insertion. The design is based on requirements and conditions, which determines the working type of the cell. The robot cell must work with pallets or protection boards with dimensions of 1000 x 1000 mm and height up to 1000 mm. Panels, which are being placed in the box, are side and top panels, as they have the biggest weights of all components.

The concept sketch is presented below:

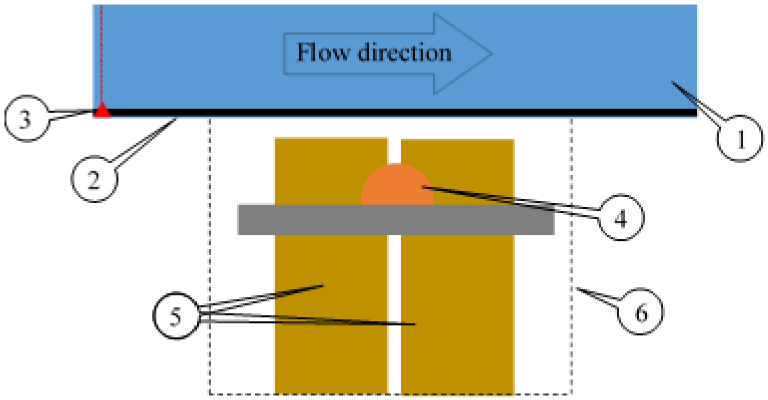


Fig. 42. Concept of the robot cell

The cell consists of the main parts: packaging conveyor (*1*), reference line (*2*), box detection (*3*), wall-mounted robot (*4*), lifting platform with driven roller conveyor (*5*) and safety fence (*6*).

The robot cell works along with the complete packaging line. Stacks are brought to roller conveyors (*5*), which are equipped with lifting platforms. This is done to maintain the same height level for the robot. It allows to reduce the travel distance and increase the cycle time. The robot (*4*) is mounted on the vertical plane, on a specially designed frame, as this allows to reduce the overall cell dimensions. Boxes are being transported on the conveyor (*1*) and are along with the reference line (*2*), this provides consistency for box crosswise position. The lengthwise position of boxes is provided by a combination of a sensor (*3*) and conveyor (*1*) with encoder. When a box passes the sensor (*3*), the position can be calculated because of an encoder and monitored along the conveyor (*1*), as the speed is constant. With this data, the robot can track boxes and perform the given task of inserting panels.

For robot selection, maximum reach and maximum payload was taken into consideration, as of needed task to perform. The ground reach was set 2000 mm and the maximum payload – 40 kg. The reach was determined according to plausible mounting places, and the weight is related to panels. It was taken that the heaviest panel can reach 15 kg. In addition to this, a gripper needs consideration. After research of available products, 6-axis Kuka KR 50 R2100 was selected. As it is fulfilling the requirements, additionally technical supervision and support are available in Lithuania, which was not the case with other manufacturers. Technical specification of the robot is provided in Table 18.

Table 18. Kuka KR 50 R2100 technical specifications

Maximum reach, mm	**Maximum Payload, kg**	**Rated payload, kg**	**Pose repeatability, mm**		**Weight, kg**
2501	61	50	±0,05		533
Axis A1 speed, °/s	**Axis A2 speed, °/s**	**Axis A3 speed, °/s**	**Axis A4 speed, °/s**	**Axis A5 speed, °/s**	**Axis A6 speed, °/s**
180	175	175	250	250	360

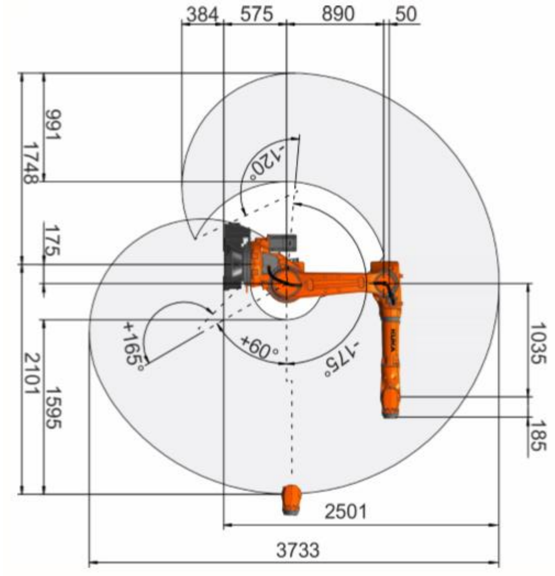


Fig. 43. Kuka KR 50 R2100 workspace graphic [28]

As the robot is applicable for wall mounting (*mounting on a vertical plane*), a frame is designed for this purpose. The frame is designed from standard SB (*300x46 mm*) beams, square (*90x90x10 mm*) and rectangular (*200x120x10 mm*) tubes with addition to metal plate (*825x700x75 mm*) for robot mounting.

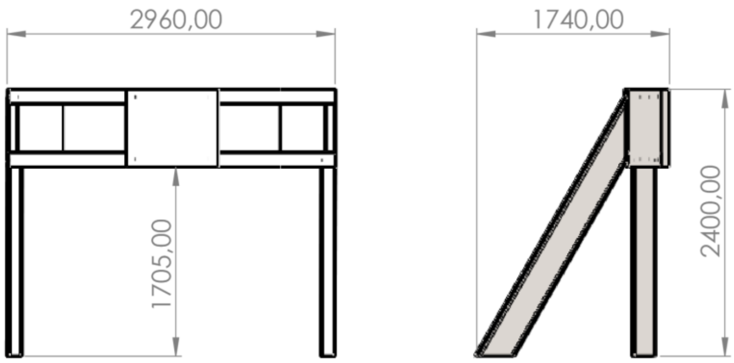


Fig. 44. Sketch of robot‘s frame

Since the frame will have to supply structure with loads applied from the robot, simulation analysis (*Finite Element Method*) was done in order to check whether the frame is sturdy enough to withstand applied forces and it is suitable for robot's precision, which should not be more than 0,3 mm.

For simulation, the material type was selected – plain carbon steel (*Elastic modulus – $2,1*10^{11}$ N/m^2, Shear modulus $7,9*10^{10}$ N/m^2, Density 7800 kg/m^3*). The fixtures were applied to main support columns and support SB beams, which are fixed to the ground. The frame itself was given a gravity force in relation to its weight centre. External forces were placed according to the robot's centre of mass ($x_1=788$ *mm*) and the maximum reach ($x_2=2501$ *mm*). The forces were calculated considering the robot's weight ($m_1=533$ *kg*) and maximum payload ($m_2=61$ *kg*). Evaluating the safety factor, the forces F_1 and F_2 were selected 5750 N and 650 N accordingly.

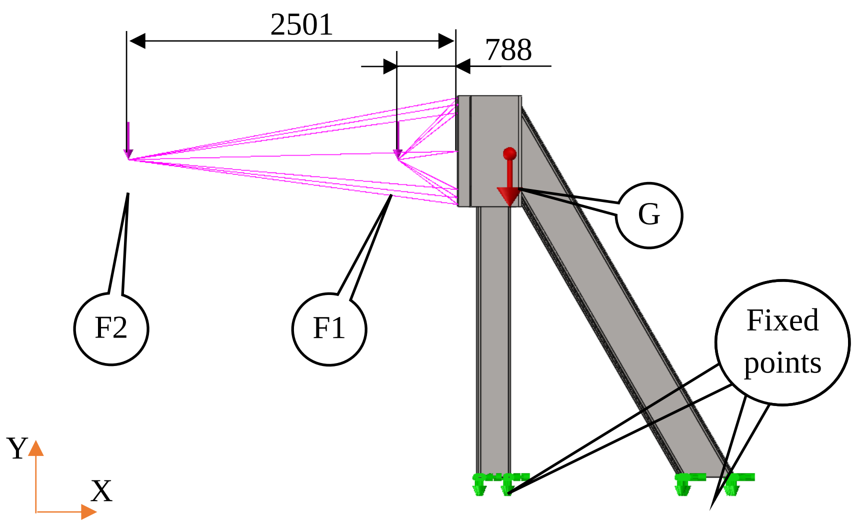


Fig. 45. Simulation scheme for the frame

With earlier mentioned constraints and external loads, the simulation was done for stress, displacement and safety of factor evaluation.

From the graphical illustration of stress, Figure 46, we can determine that the biggest stress is placed on the centre of the frame where the robot mounting position is. Largest rated stress – $1{,}482 * 10^7$ N/m^2. In addition to this, the factor of safety can be calculated, as the metal's yield strength is provided. The calculated value for the factor of safety is 13,72, which allows to make an assumption that the frame is suitable.

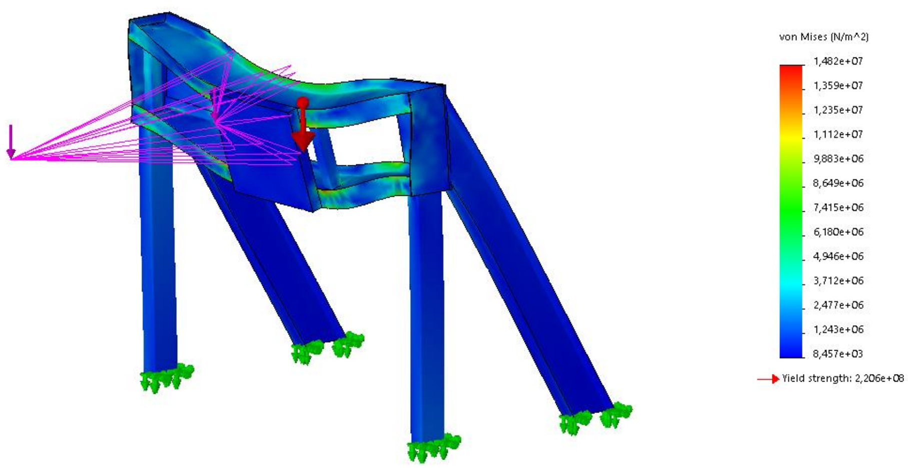


Fig. 46. Graphical illustration of stress distribution on the frame with external load

The displacement graph, Figure 47, indicates that the robot mounting place has a displacement of 0,247 mm. The displacement value is vital for the robot's precision, as it might have an impact of placing the panel in the correct position. However, as the acceptable positioning precision is 0,3 mm, and the initial robot's precision is ±0,05 mm and evaluating that external loads were accessed with 10 % safety, this frame's displacement can be accepted.

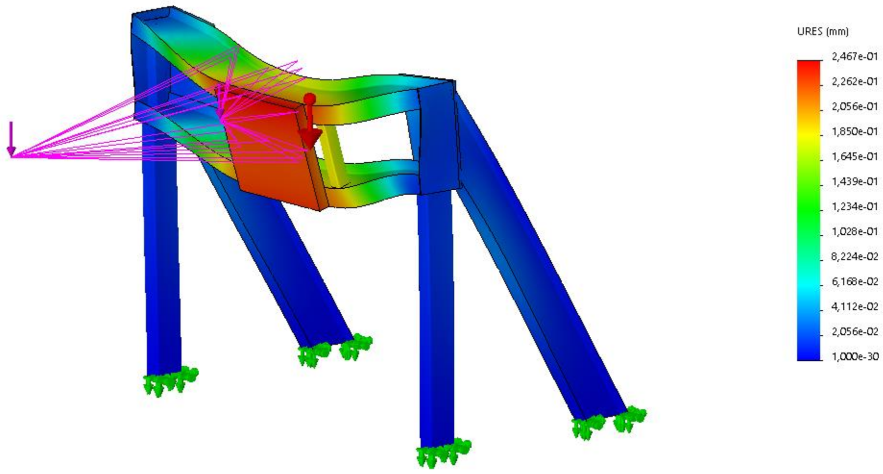


Fig. 47. Graphical illustration of displacement distribution on the frame with external load

The gripper was designed in a way to offer flexibility in panel collection and to maintain desired capacity. The gripper's frame is assembled from standard 40x40 mm aluminium profiles and mounting plate for the robot.

For vacuum system, vacuum ejectors were selected, as of low weight, high vacuum power and easy installation, though high compressed air consumption. The vacuum cups are arranged in a chess layout for flexibility, as it would be easier to pick up panels with grooves or other technological holes and cavities.

For considering the lifting power that the gripper needs to offer, weight of 20 kg is estimated. For calculating the lifting force, the safety factor of 1,5, system acceleration a=3 m/s^2 are evaluated. A lifting force F=2833 N is needed. Considering it, Festo 10-L-T3-PQ2-VA4-RO1 vacuum ejectors and Festo 525996_ESS-50-BT-G1_4 suction cups were selected. As a single piece offers 115 N suction power with 6 bars of pressure, the gripper is equipped with 26 vacuum ejectors.

Technical description of the gripper is provided in the table below.

Table 19. Gripper's technical parameters

Type	Suction force, N	C. Air consumption, Nl/min	Number of vacuum ejectors	Weight, kg	Dimensions, mm
Vacuum ejector	2990	1650	26	21	818 x 216 x 286

The gripper's vacuum cups are grouped into 4 parts, each controlled independently with electronic valves. This allows to turn on and off the vacuum cups according to the panel size. Also, with this configuration, several panels can be collected at a time. Example of collecting to pieces at a time is possible for the desired panels (*549 x 450 mm*), Figure 48.

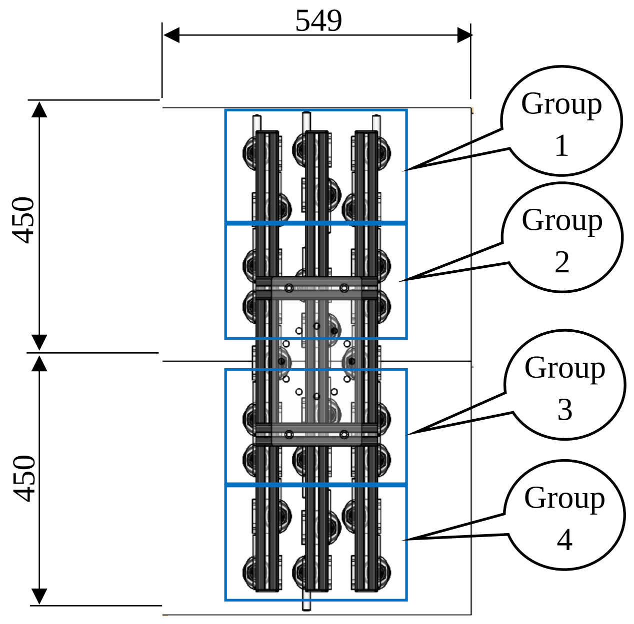


Fig. 48. Gripper‘s vacuum cups arrangement

Because of the stack height (1000 mm) and the need to maintain the same level of stack regarding to the packaging conveyor (900 mm). Lifting platforms are placed in pits, which also provides additional space for robot movement.

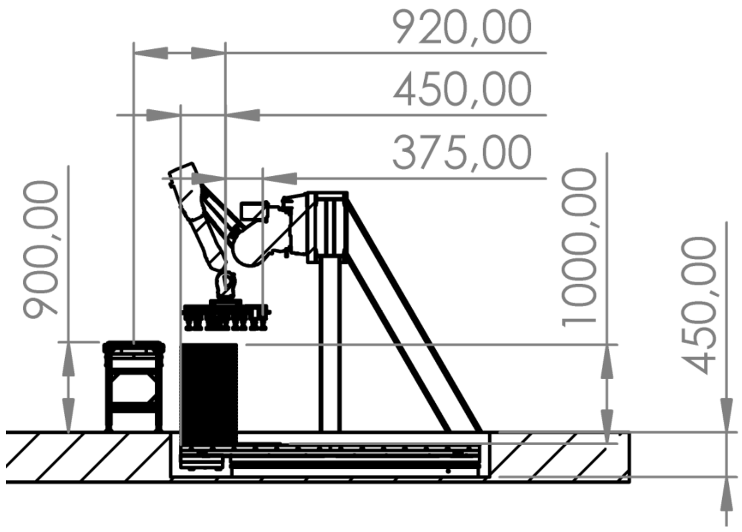


Fig. 49. Robot cell dimensions and placement

For cycle time evaluation, calculation scheme is created. For the cycle time, distances are measured of each axis, and step-by-step position is created. Cycle time evaluation allows to estimate the needed time to complete one cycle, which consists of these main tasks – panel collection, box detection and panel insertion. However, the cycle evaluation consists of additional tasks that provide more accurate and precise calculations. The evaluated speed is considered an average 250 ^{O}/s, as multiple axles are being moved at a time. The calculated theoretical cycle time might deviate from practical, as it is challenging to evaluate all parameters.

Table 20. Robot cycle time analysis

No	Description	Distance to travel, mm			Speed, $^{O}/s$	Time, s
		x	y	z		
1	Home position	0	0	0	-	-
2	Pick-up waiting pos.	0	+720	0	250 $^{O}/s$	0,35
3	Pick-up pos.	0	+720	-50	250 $^{O}/s$	0,2
4	Vacuum suction	0	+720	-50	250 $^{O}/s$	0,4
5	Lift up pos.	0	+720	+10	250 $^{O}/s$	0,25
6	Insert waiting pos.	+905	0	+10	250 $^{O}/s$	0,8
7	Determining box pos.	-	-	-	250 $^{O}/s$	0,5
8	Insert pos.	+905	0	-20	250 $^{O}/s$	0,2
9	Lift up pos.	+905	0	+10	250 $^{O}/s$	0,2
10	Determining box pos.	-	-	-	250 $^{O}/s$	0,5
11	Insert pos.	+905	0	-20	250 $^{O}/s$	0,2
12	Lift up pos.	+905	0	+10	250 $^{O}/s$	0,2
13	Pick-up waiting pos.	0	+720	0	250 $^{O}/s$	0,8
Total cycle time						4,6

If considering the maximum line capacity, 23 boxes/min, width box dimensions of 760 mm and minimum gap between boxes, the lines speed reaches 20-21 m/min or 0,33-0,35 m/s. Evaluating that the robot is capable of performing its task through-out the whole-cell width – 2900 mm, there is a time window for performing a task of 8,8 s. Additionally, with shortest 300 mm boxes, the time window is 5 s.

According to cycle time calculation, the robot can maintain the needed performance rate, as the cycle time with double parts is around 4,3 s.

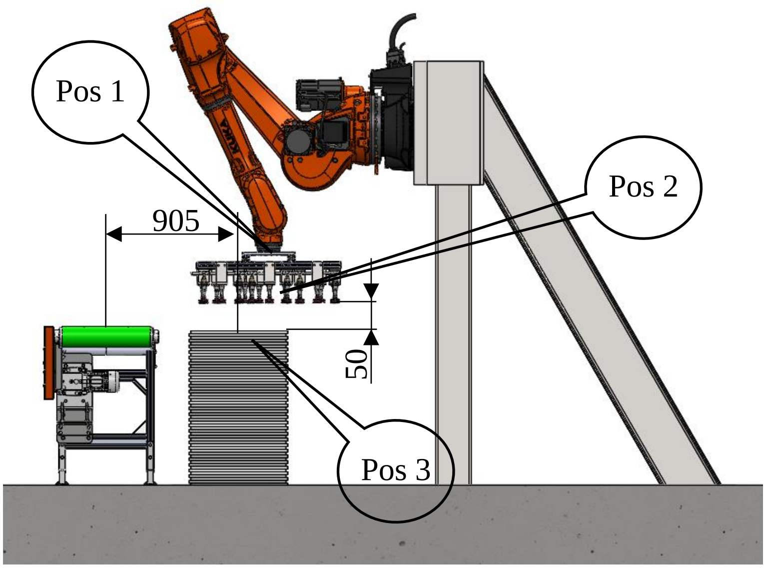


Fig. 50. Robot cell's working positions for cycle evaluation (1)

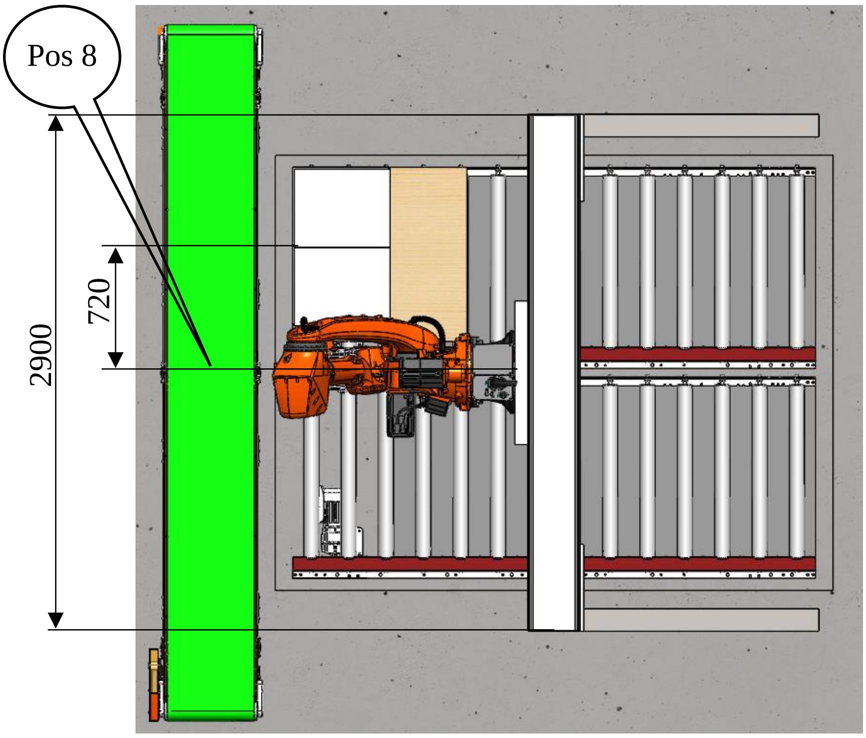


Fig. 51. Robot cell's working positions for cycle evaluation (2)

For estimating the cost of the robot cell, raw materials, manufacturing, assembly, electrical components are evaluated in Table 21.

Table 21. Robot cell cost estimation

Description		Cost, Eur.
Raw material	Robot	22 000
	Gripper	3 000
	Frame	1 500
	Lifting platform (*2x*)	2 500
	Safety fence	2 000
	Electrical components	4 000
Manufacturing and assembly		11 000
Software programming		5 500
	Total	61 000

Concluding the cost estimation, 70 % of the total cost are the raw material expenses. Manufacturing and assembly make 20 %, while a software programming is 10 %. Technical specification of the robot cell is provided in Table 22.

Table 22. Technical specification of robot cell

Position	**Dimensions, mm**	**Weight, kg**	**Capacity, cycles/min**	**Electrical power, kW**	**C. air consumption, Nl/min**
Robot cell	3000 x 2950	-	12	15	1650
Frame	1620 x 2950 x 2400	1750	-	-	-
Lifting platform (*2x*)	3000 x 1000 x 350	850	-	-	-

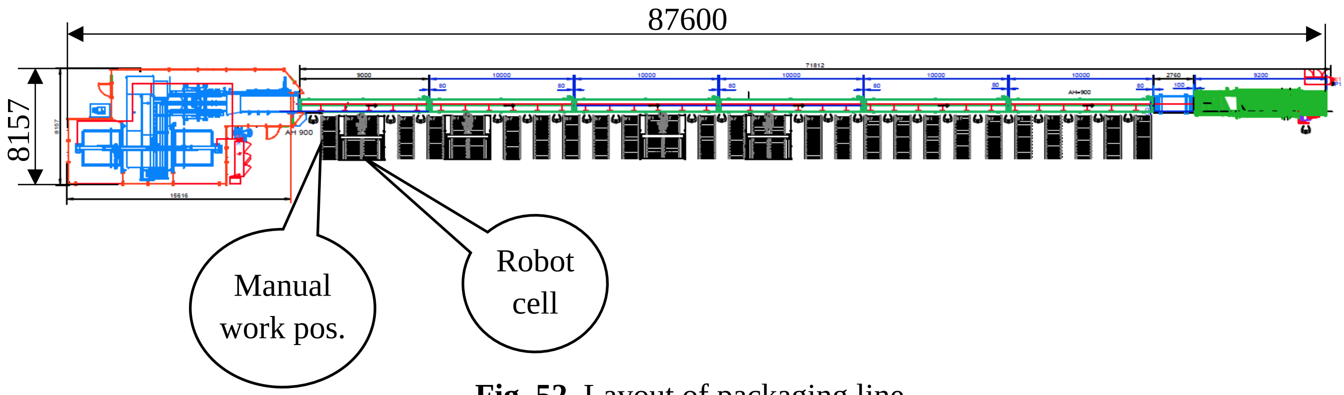


Fig. 52. Layout of packaging line

As shown in Figure 52, each packaging line consists of 22 possible manual work positions and four robot cells. The robot cells were arranged to fulfil the analysed article. However, additional manual work positions were added in order to have flexibility for new articles or structural changes in existing ones.

3.7. Automated outfeed system

The packaging lines' outfeed defines a combination of box collecting, sorting and unloading tasks which are performed in order to compile a complete stack on pallet, according to an article. As being part of complete packaging lines, the system must fulfil the performance requirements, in addition to this, it must retain the automation level to reduce manual labour.

For designing the automated outfeed system, same specifications are applicable, such as, capacity (*23 boxes/min*), box sizes (*300-2000 x 400-800 x 40-100 mm*) and the gap between boxes (*Min. gap 500 mm*). Parameter that must also be evaluated is the box weight (*max. 80 kg.*). Additionally, the system must fit in the dedicated floor space, which is shown in Figure 53.

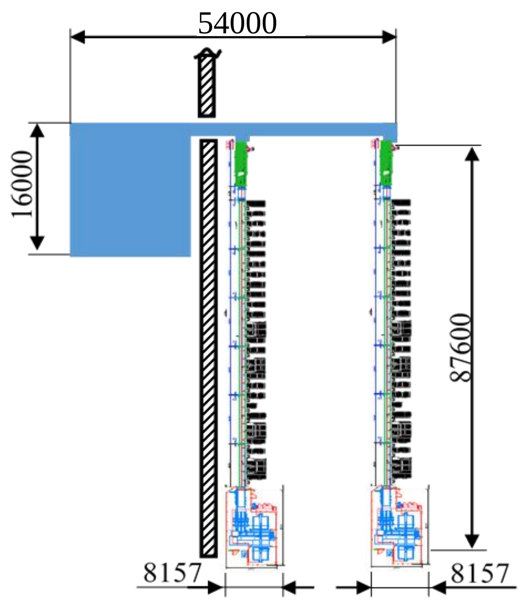


Fig. 53. Sketch layout of packaging lines with outfeed system *Note: sketch is not in scale*

The automated outfeed system consists of several sections which are related to different tasks. It must include transportation and sorting, overlap supply, pallet supply, box unloading and pallet transportation.

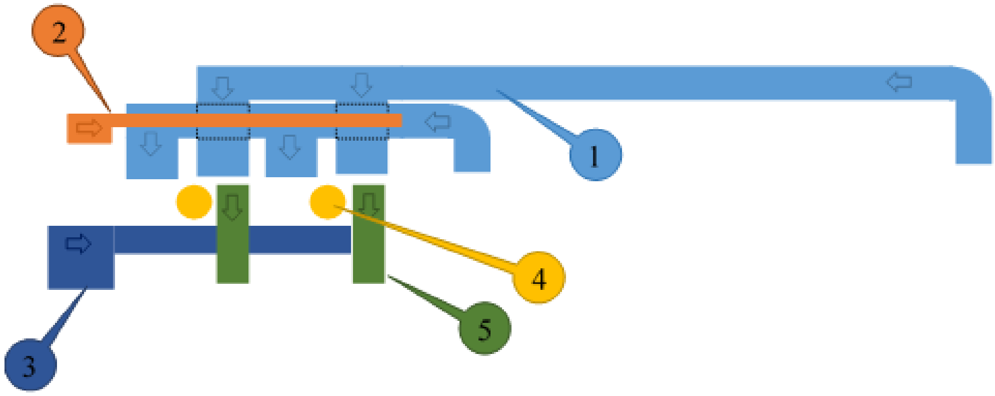


Fig. 54. Sketch layout of an automated outfeed system

Position 1 is the transportation and sorting part. The purpose of it is to transport the boxes from the box closing machines to the unloading area. The system must be designed in a way that each packaging line can work with each robot, as this provides a possibility to work with different box sizes, additional flexibility is increased in that matter. Position 2 is the cardboard overlap supply, which distributes the material according to the need for robots. The cardboard overlaps might be used for some articles to provide additional protection and binding feature between the boxes once stacked on a pallet. Position 3 is the pallet distribution system which's task is to provide cardboard pallets for robots. The pallets are used for securing, stacking, and transporting the final product. Position 4 – automated unloading system. The system consists of 2 robots with vacuum grippers which are collecting boxes from sorting stations and stacking them on pallets according to the article. Additionally, the robot performs tasks such as cardboard overlap collecting and placement and pallet collection. Position 5 is the pallet transportation system which transports stacked pallets to further technological process.

The goal of the automated outfeed system is to maintain the desired performance rate in order not to reduce the capacity for complete packaging line. In addition to this, it must provide integrity for the overall line, as the control of each position and each machine must be available from the centre control panel.

3.7.1. Transportation and sorting part

The transportation and sorting part performs a logistical task of moving the boxes from the box closing machine and sorting and distributing them to the unloading area accordingly. As the system is limited in dedicated space, a decision was taken to make it 2 level system, which would provide possibilities in fitting the conveyors with the ability to link packaging lines with adequate unloading zones.

The transportation and sorting part consists of:

1. Angle roller conveyors
2. Roller conveyors
3. Roller conveyors with cross drive

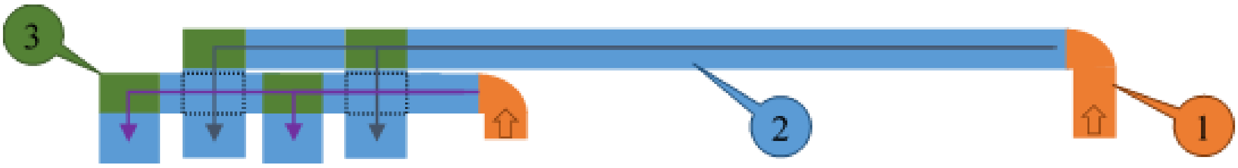


Fig. 55. Transportation and sorting part layout

Angle roller conveyor is designed in a way to transfer materials in a desired curve. For this purpose, tapered rollers are used, which enables the possibility of turning the outgoing boxes by 90^{O} [29].

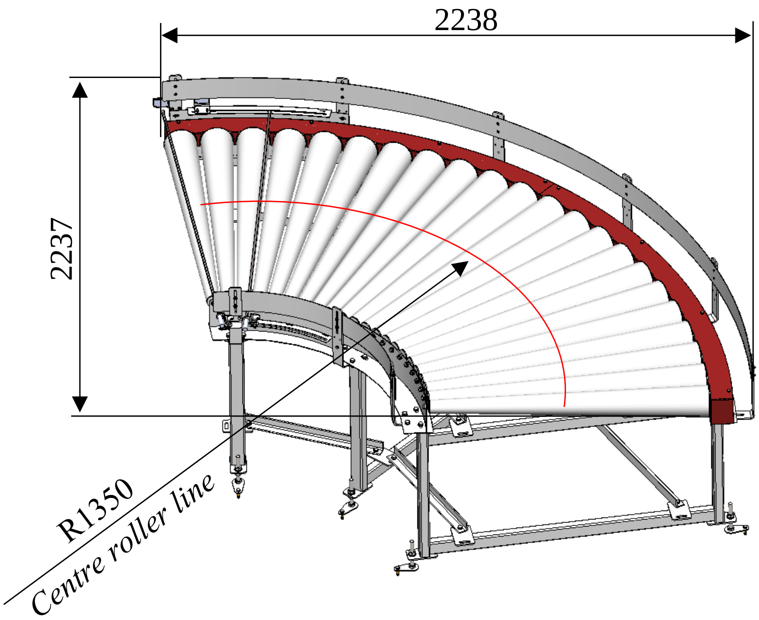


Fig. 56. Angle roller conveyor

The construction is based on standard rectangular tubes (*40x60x3 mm.*) and L shape profile (*40x40x4 mm.*). Additional constructional elements are used for technological and integrity purposes. The conveyor is chain driven and equipped with 2 AC gearmotors (*0,37 kW, 15 Nm*). This is done to have control of turning radius, as different length boxes, require different speeds.

Technical description of the angle roller conveyor is provided in Table 23.

Table 23. Technical specifications of angle roller conveyor

Drive type	Dimensions, mm	Weight, kg	Electrical power, kW	Speed*, m/min	Maximum load, kg/m
Chain	2238 x 2237 x 900	405	0,75	21 - 50	350

**Note - speed is considered in the centre roller line*

Roller conveyors are designed in a way to transport the articles to sorting and unloading areas. The conveyors' construction is based on standard profiles and standard lengths. This solution allows to reduce not only the raw material and manufacturing expenses but also time for designing and manufacturing is lowered in that matter.

There are three main roller conveyor types which are used in the system:

1. Roller conveyor for transporting

They are used for material movement. Driving motion is provided by a shaft, which is driven by an AC motor (*0,75 kW*), via a belt. Maximum load – *200 kg/m*, working width – *850 mm*, speed – *20-60 m/min*.

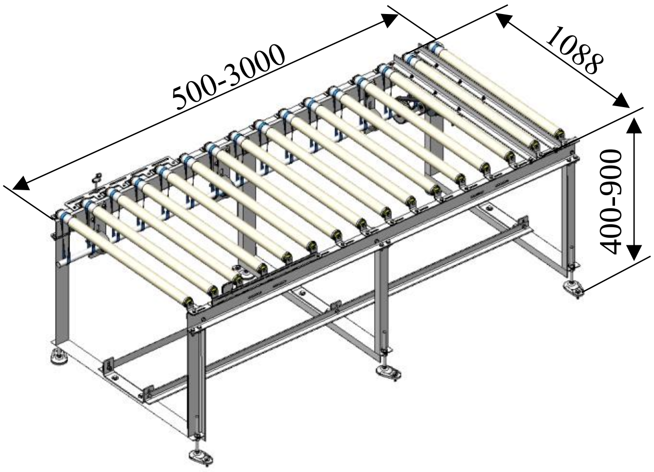


Fig. 57. Roller conveyor for transporting

2. Chain roller conveyor

They are used for material movement above aligning roller conveyor. For this reason, clearance below the conveyor was considered essential and constructional support in the middle was not available. Conveyors integrity was increased by using bigger size constructional materials. Conveyor uses chain drive with AC gear motor (*0,55 kW, 11 Nm*). Maximum load – *200 kg/m*, working width – *850 mm*, speed – *20-55 m/min*.

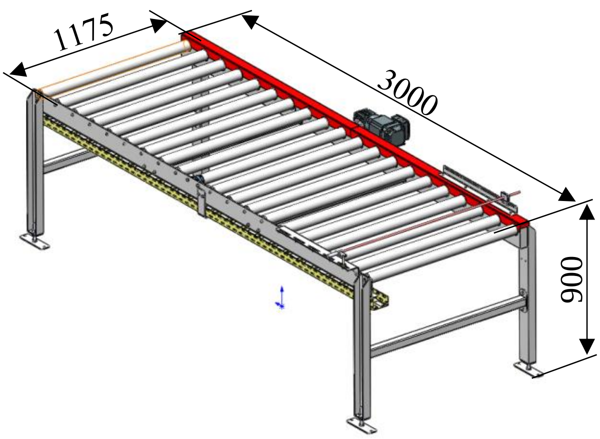


Fig. 58. Chain roller conveyor

3. Roller conveyor with alignment

These roller conveyors are used as a pick-up place for robots as they have alignments mounted both lengthwise and crosswise. Belt drive is used in this type of roller conveyor. AC motor (*2 x 0,75 kW*). Maximum load – *200 kg/m*, working width – *850 mm*, speed – *20-60 m/min.*

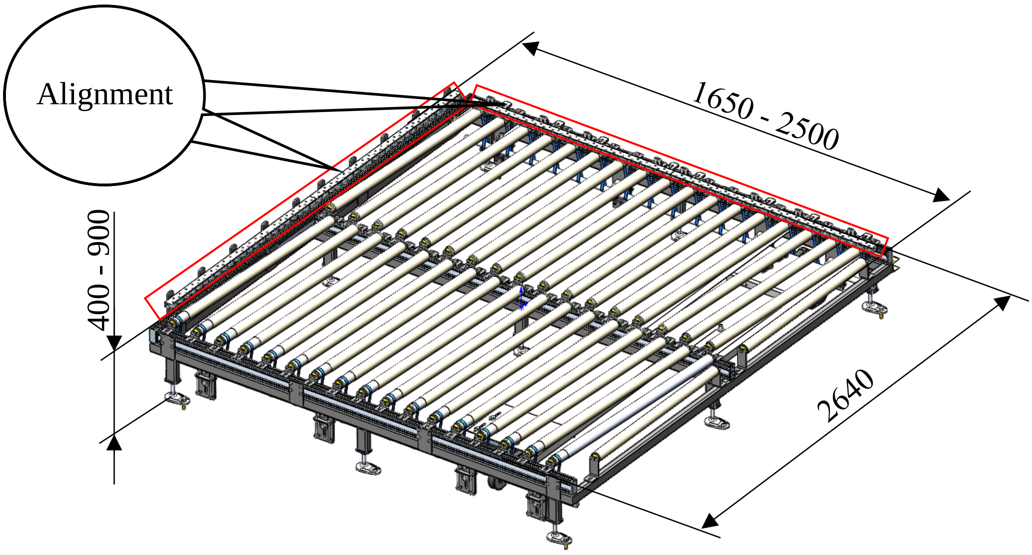


Fig. 59. Roller conveyor with alignment

The conveyors are arranged and positioned in a way to fulfil the requirements of moving the boxes from the box closing machine to the unloading area. The conveyor line which transfers the materials from line 2, is designed in descending height level, which allows the possibility of using both unloading zones, without interrupting the flow. The height difference between the conveyors is 500 mm. The system contains 19 roller conveyors (*13 roller conveyors for transporting, 2 chain roller conveyors and 4 roller conveyors with alignment*). The layout is provided in Figure 60.

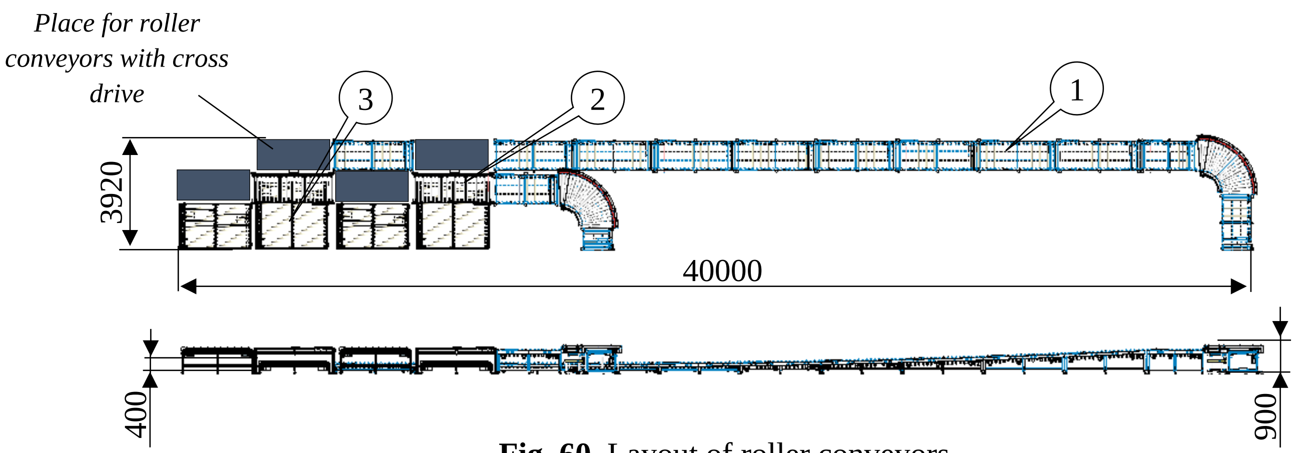


Fig. 60. Layout of roller conveyors

Roller conveyors with cross drive are designed for sorting task. It is able to move the materials in 2 directions – direction of flow and 90^{O} direction. It is used depending to which unloading zone, the materials need to be transported. The conveyor contains 2 main units: lengthwise drive, for moving the materials in the flow direction and cross drive for moving the materials in 90^{O} direction.

When the material needs to change the movement direction, stopping base is raised, which allows to align the boxes. Then, the pneumatic cylinder raises the cross drive, which transports the boxes to the desired unloading zone. Lengthwise drive consists of rollers driven by a chain and an AC gear motor (*0,75 kW, 14 Nm*), while the cross drive is equipped with tabletop chains, which is powered by AC gear motor (*0,75 kW, 25 Nm*). Maximum load – *300 kg/m.*, working width – *850 mm*, speed (*lengthwise*) – *20-60 m/min*, speed (*crosswise*) – *20-25 m/min.*

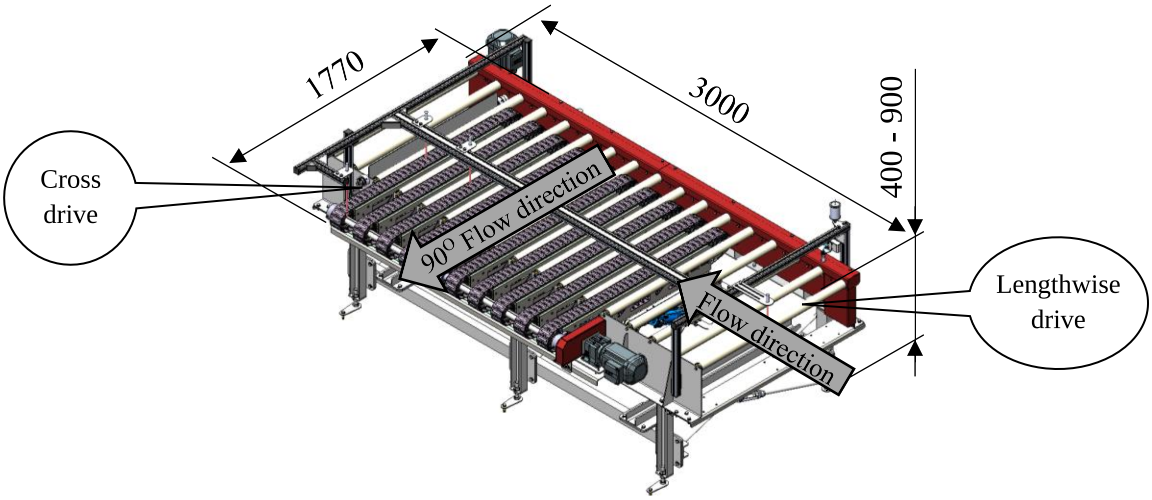


Fig. 61. Roller conveyor with cross drive

3.7.2. Automated cardboard overlap supply

Automated cardboard overlap supply is a system that automatically distributes single cardboard overlaps for robots. Cardboard overlaps are used in between stack layers in order to provide additional protection and binding for stability.

Cardboard overlaps dimensions are 500 x 400 x 3 mm. The system must provide the material with a performance which would now reduce the overall line's capacity. Considering it, the overlaps must be provided every 5 s.

The system divides into three main parts:

1. Material infeed zone.
2. Feeding zone.
3. Transportation zone.

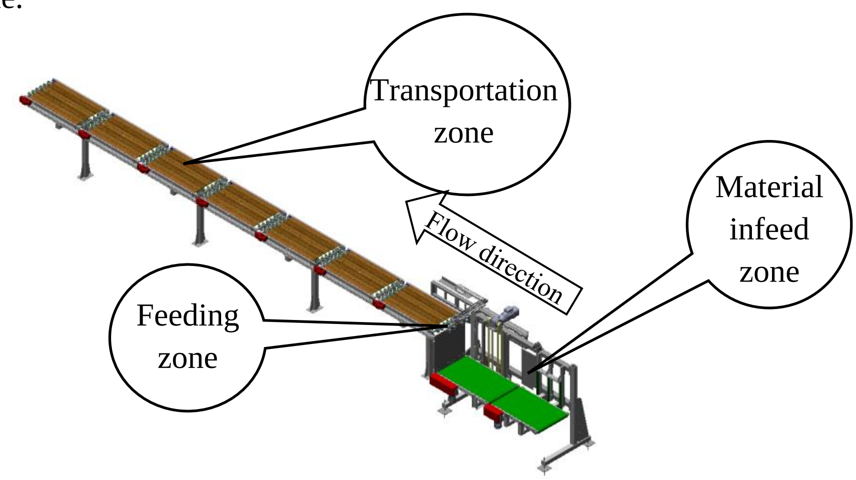


Fig. 62. Automated cardboard overlap supply

Material infeed zone is dedicated to manual material insertion, which in this case, is a stack of cardboard overlaps. Maximum stack dimensions – 600 x 700 x 600 mm. Stack is referenced by aligning both lengthwise and crosswise manually by pushing it to reference panels. The aligned stack is then moved to the feeding zone, which contains lifting belt drive and vacuum gripper. Stacks are lifted to the height, which allows the vacuum gripper to swipe the top overlap layer on the transportation belts. Further on, the transportation belts move the cardboard overlaps to a designated place.

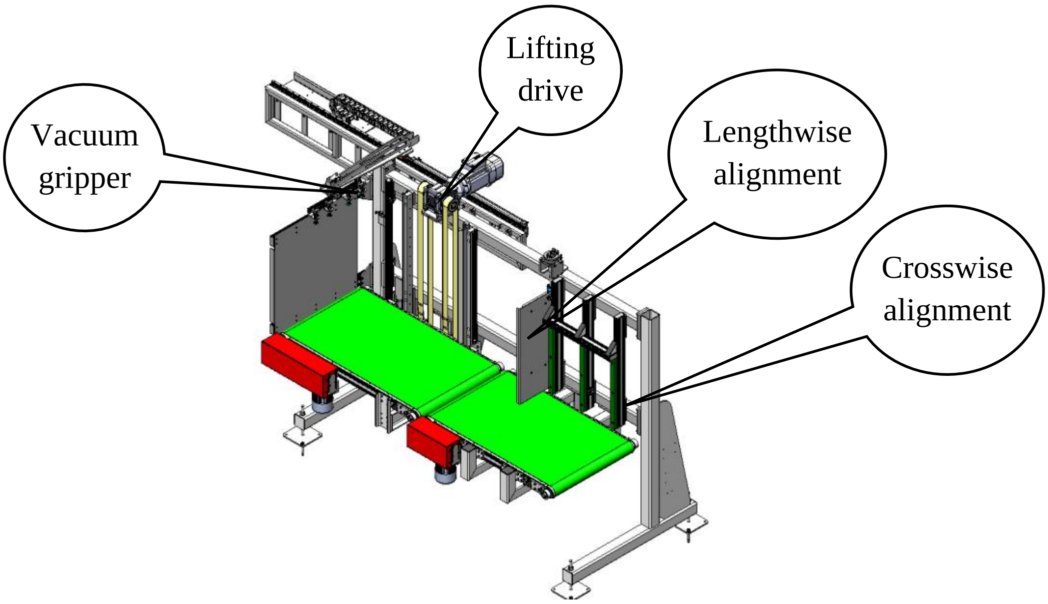


Fig. 63. Cardboard overlap supply infeed and feeding zones

Transportation zone is made of 7 belt conveyor sections. As only two sections are used as a pick-up place, others can be used to maintain a buffer. The belt conveyor is equipped with AC gear motor (*0,12 kW, 5 Nm*), which allows to have a speed up to 55 m/min. Considering that the complete length of the transportation zone is 10170 mm, and a single section is 1470 mm, the capacity that can be reached is 28 pcs/min, which satisfies the requirement.

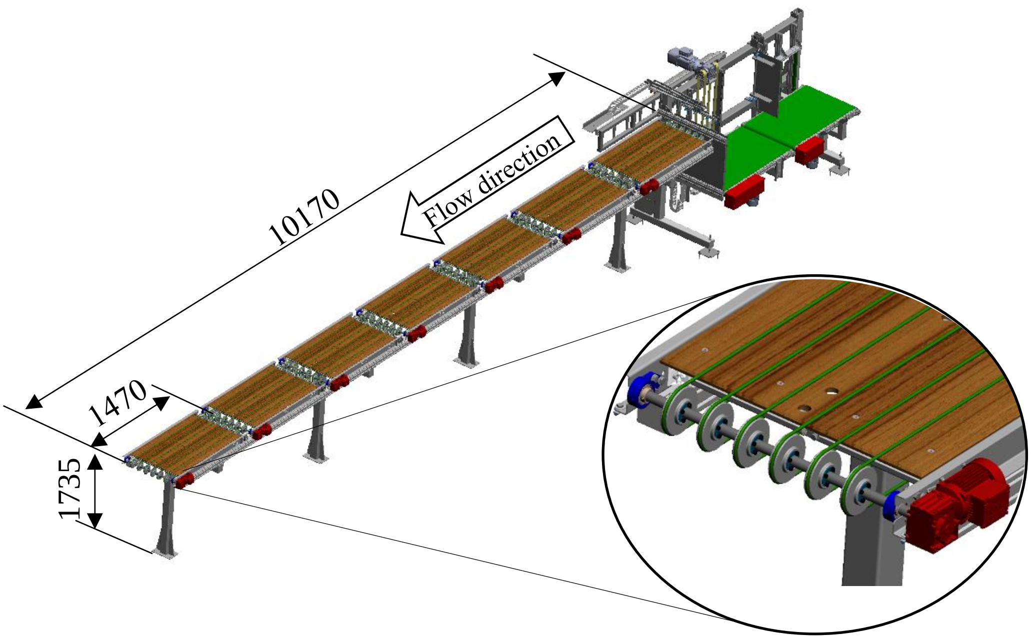


Fig. 64. Transportation zone of automated overlap supply system

3.7.3. Pallet distribution system

Pallet distribution system is an automated system for distributing and transporting pallets to designated places for robots. Pallets are used for stacking final products, which provides protection and transportation possibility in further procedures.

The system contains:

1. Infeed zone.
2. Belt conveyor.
3. Belt conveyor with alignment.

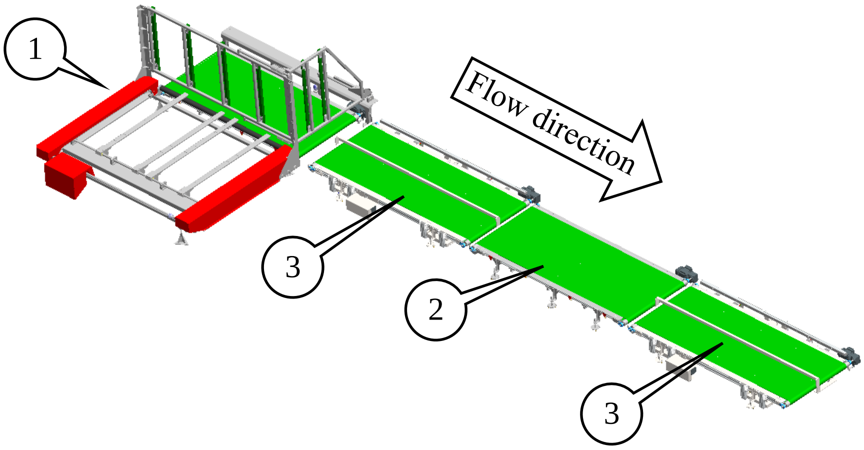


Fig. 65. Pallet distribution system

The infeed zone contains belt-driven forks and lifting platform with belt conveyor. The stack of pallets is positioned and aligned on the conveyor which is then raised to separate the bottom pallet from the complete stack with a use of forks. Once the forks are holding the upper stack, the belt conveyor descends to a position where the bottom pallet can be transferred to other positions.

Belt conveyor with alignment is used for positioning the pallet in the correct place, which then can be picked-up with the robot. The system contains two belt conveyors with alignment, as two robots needs to be served.

Technical specification of the system is provided in Table 24.

Table 24. Technical specification of pallet distribution system

Position	Dimensions, mm	El. Power, kW	Capacity, pcs/min
Infeed zone	3890 x 2915 x 1630	1,15	5
Belt conveyor	2900 x 1250 x 300	0,37	
Belt conveyor with alignment	2900 x 1350 x 370	0,75	

3.7.4. Pallet transportation conveyors

Pallet transportation conveyors are designed for transportation of stacked pallets from the unloading area for further technological processes.

The conveyors use chain driven rollers and are capable of withstanding loads up to 1200kg/min. The frame of the conveyor is based on standard UPE120 and 50 x 50 x 3 mm tube profiles.

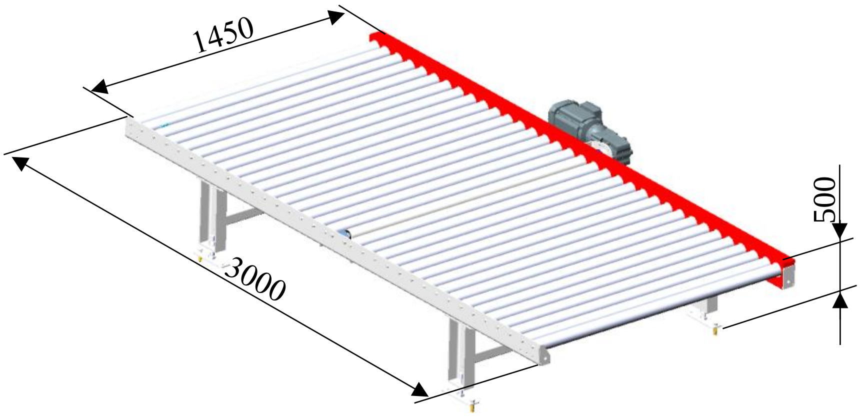


Fig. 66. Pallet transportation conveyor

The technical specification is provided in the table below.

Table 25. Pallet transportation conveyor ‘s technical specification

Dimensions, mm	Weight, kg	El. power, kW	Torque, Nm	Maximum load, kg/m	Speed, m/min
3000 x 1450	380	0,75	67	1200	15-22

3.7.5. Automated unloading system

The automated unloading system is responsible for collecting the boxes and compiling a complete stack on a pallet. Additionally, supplemental tasks are required, such as cardboard overlap insertion and pallet collection.

Considering the technical requirements which were discussed in previous chapters, the system must be able to maintain 23 boxes/min capacity and cope with adequate boxes (*400-1600 x 300-600 x 40-100 mm, weight up to 40 kg per box*) with the precision of ±0,5 mm. Due to high capacity rate, the automated unloading system contains a pair of robots, as one would not be able to perform at the desired rate. KUKA 5-axis KR180 R3200 robot were selected due to high payload (*180 kg*) and high reach distance (*up to 3195 mm.*), with speed 112-242 ^{O}/s.

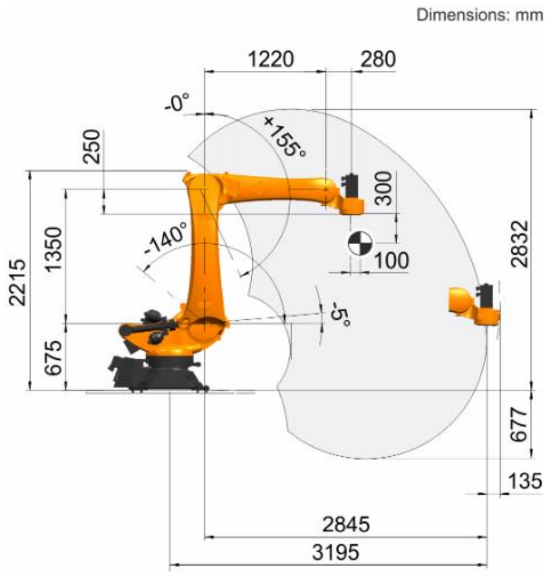


Fig. 67. Kuka KR180 R3200 workspace graphic [28]

For material handling vacuum gripper is designed. The construction is similar, which is used in panel insertion robot cell. Standard aluminium 40 x 40 mm and 40 x 80 mm profiles are used. For vacuum system, vacuum ejectors were selected, as of low weight, high vacuum power and easy installation, though high compressed air consumption. Considering the lifting weight, maximum two boxes with 40 kg each, is estimated. Evaluating the safety factor (1,5) and system acceleration a=3 m/s^2, the needed suction force F=11 500 N is required. According to the calculated suction force, Festo VN-20-H-T6-PQ4-VQ5-RO2 vacuum ejectors with combination in Festo 525996_ESS-50-BT-G1_4 suction cups were selected. With the system pressure of 6 bars, single pieces of vacuum ejector is capable of generating 161 N of lifting force. In this matter, 72 vacuum ejectors are arranged in order to overlay an area of 1 m^2. Technical description of the gripper is provided in the table below.

Table 26. Gripper‘s technical parameters

Type	Suction force, N	C. Air consumption, Nl/min	Number of vacuum ejectors	Weight, kg	Dimensions, mm
Vacuum ejector	11 600	7056	72	75	1768 x 790 x 450

The gripper’s vacuum system is grouped into six parts, each controlled independently with electronic valves. This allows to turn on and off the vacuum cups according to the panel size. Also, with this configuration, several panels can be collected at a time.

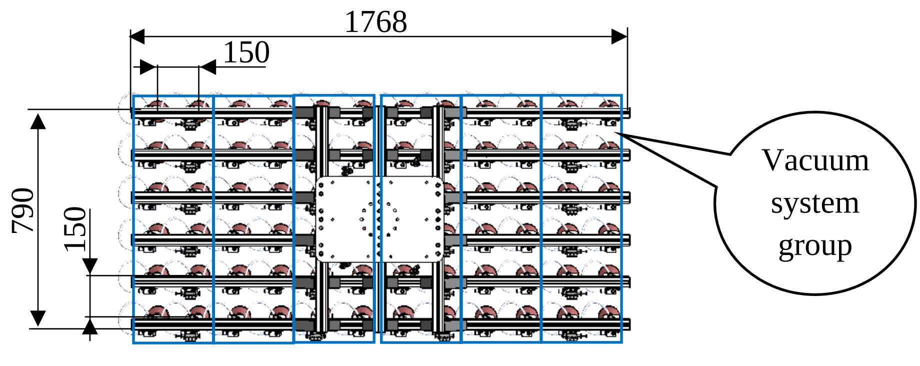


Fig. 68. Vacuum gripper for box unloading

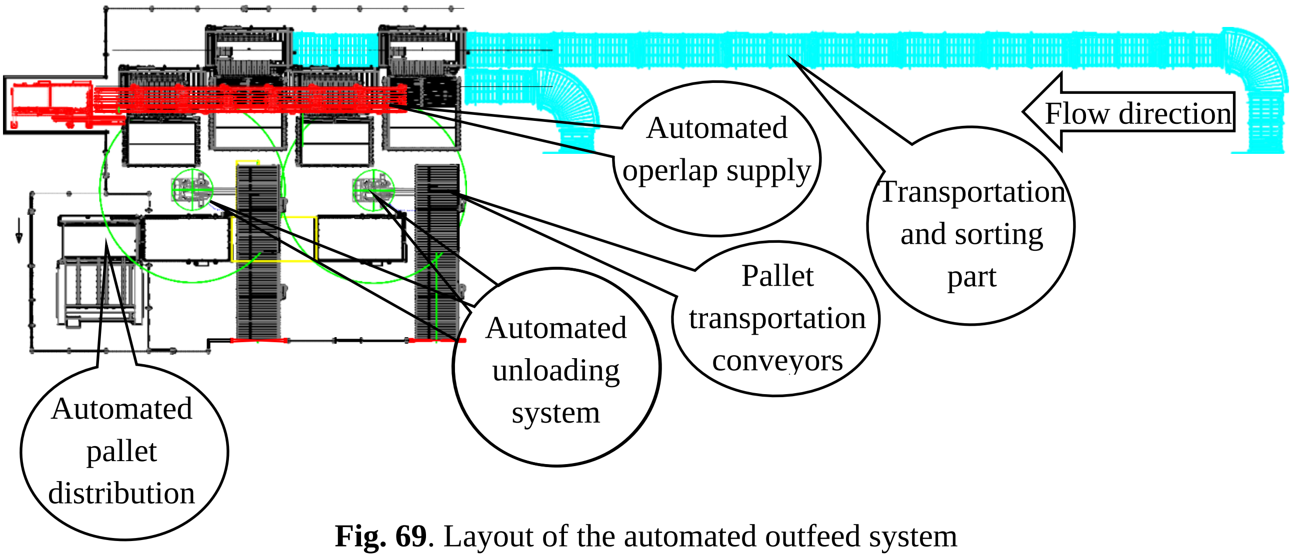


Fig. 69. Layout of the automated outfeed system

Figure 69 illustrates the layout of the automated outfeed system with all parts placed in according positions. Drawing of the layout is provided in Appendix 3.

For performance evaluation, calculating scheme with each position was compiled. This allows to make calculations of each movement duration and how long the complete cycle takes time. As the system is equipped with two robots, the calculations will be based on one, because the positions for both robots have identical distances. However, 2 cases are evaluated: when working with one dimensions box and the second when the dimensions are different, and the pallet contains both of them.

Table 27. List of box unloading positions for cycle calculation

No	Pos. name	Description	Position, mm		
			x	y	z
1	H	Home position	0	0	0
2	A	Box pick position, conveyor 1	+2000	-2500	+530
3	B	Box pick position, conveyor2	+750	-2000	+3400
4	C	Pallet collection position	-900	-2700	+950
5	D	Pallet placement position	-400	-2500	0
6	E	Cardboard overlap collection position	+2800	-1300	+800

Step-by-step cycle calculation for both cases are provided in appendixes. Appendix 4, shows the cycle when working with one-size boxes from A and B stations, handling two boxes at a time. Appendix 5, shows the cycle when working with different size boxes, one size in A station, one in B.

Theoretical cycle calculations might have deviations from real cycle time, as some of the parameters are evaluated in expected average values. For example, speed is considered an average of all axles, as multiple axles are being moved at a time. Also, the given speeds are considered with a maximum load, which in real situation would not be the case.

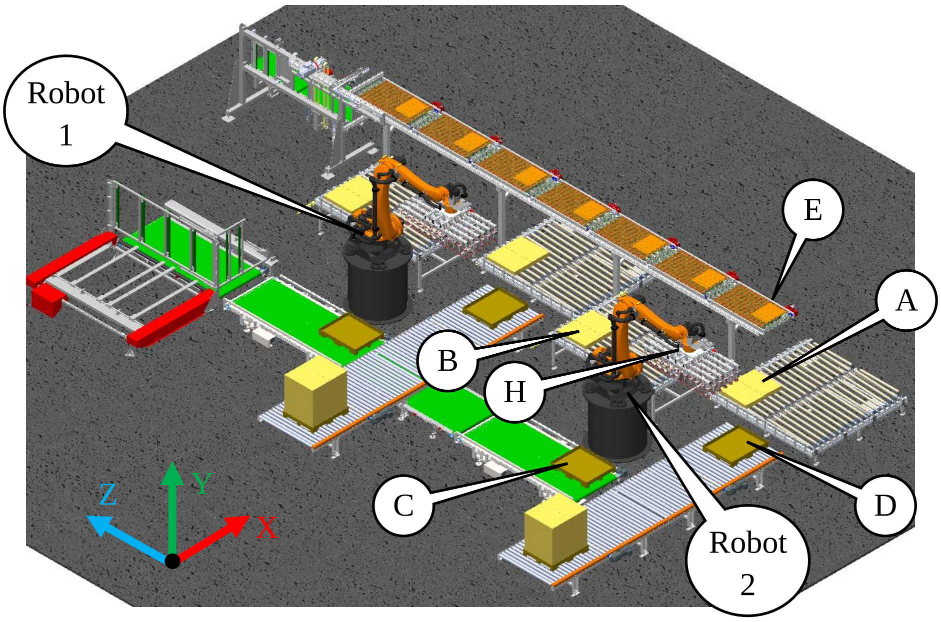


Fig. 70. Box unloading cycle calculation scheme

Considering the first case, while working with one-size boxes, the total cycle time for stacking complete pallet is 107,72 s. It consists of empty pallet preparation, stacking the boxes and inserting the cardboard overlaps layer-by-layer. When evaluating that the robot must perform at a single line's capacity – 11,5 boxes/min and the pallet contains 20 boxes, the time value which is needed to fulfil this requirement cannot be higher than 104,4 s. However, considering that empty pallet preparation takes up to 4 s. and the line is capable of buffering from 8 to 18 boxes, there is a time window of 20-40 s, which can be used for performing tasks without stopping the line. From the cycle calculation, we can determine that an average layer (*2 boxes*) placement time with overlaps is 10,8 s. If the cardboard overlap number would be reduced to half, the layer placement time could be reduced by 15-20 %, as single overlap placement takes up to 6,25 s. If analysing case 2, when working with different size boxes, the overall cycle time for completing one pallet is 130,7 s, which is 21 % higher. This is due to additional movements that robot must make for collecting boxes from A and B positions. The time for placing one layer, in this case, takes up to 13,2 s. This means that a single robot has a capacity of 9,1-11,2 boxes/min, or 18,2-22,4 boxes/min when working with both robots.

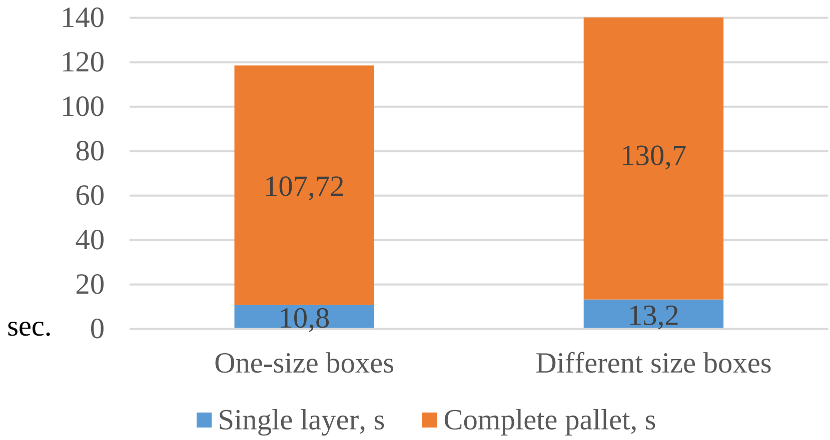


Fig. 71. Cycle time comparison between unloading one-size and different size boxes

Technical specification of automated outfeed system is provided below in Table 28.

Table 28. Technical specification of the automated outfeed system

Name	Capacity, pcs/min	Speed, m/min	C. Air consumption, Nl/min	El. Power, kW	Cost, Eur.
Transportation system	-	20-50	-	18	124 000
C. overlap supply system	28	55	100	1,5	78 000
Pallet distribution system	5	15-25	-	3	86 000
Unloading system	18,2-22,4	-	14112	45	165 000
Pallet transportation system	-	15-22	-	3	23 000
				Total	**476 00**

3.8. Overview of complete packaging line

The overall packaging line consists of two box folding machines, two packaging conveyors, including panel insertion robot cells, two box closing machines and an automated outfeed system. The machinery is positioned in the designated hall, fulfilling the requirements of both fitting in the area, and transferring the boxes directly to a warehouse.

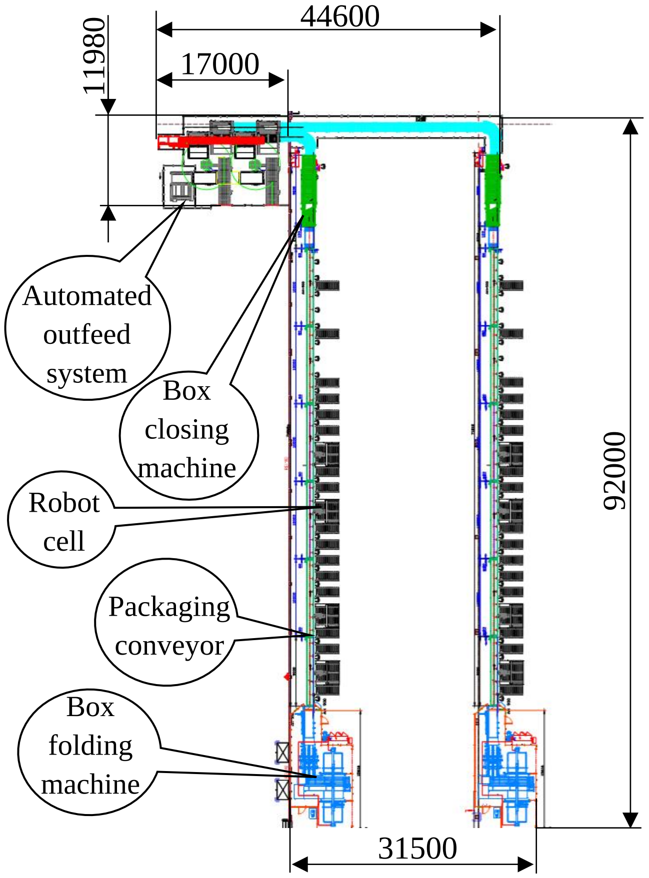


Fig. 72. Layout of the automated packaging line

The described line can reach capacity up to 18,2 - 22,4 boxes/min and is able to work with the dimension boxes 400-2000 x 200-1000 x 25-250 mm, maximum box weight – 80 kg. As the line consist of 22 work positions and four robot cells by each conveyor, articles up to 26 pieces can be packaged in this line. Though the automated outfeed system has a lower capacity than 23 boxes/min, buffer area within the system could allow to damp the stops and maintain needed performance. For operating the line, at least one operator is needed which would be able to set up the machines from a single control panel, as the system would be equipped with communication between machines. This would not only provide a simplicity in setting up the machines but also, for performance rate calculations or other parameter readings. Designed robot cells allowed to reduce the number of workers by the conveyors from 16 % to 33 %, as total of 8 robots cells were applied. Overall, the number of employees which can be placed by the line is 48 (*1 main operator, 3 operator assistants and 44 workers by the conveyor*).

4. Economic calculations

Economic calculations are used for complete project evaluation, determining the expenses which are related to machinery, savings which are gained by increases capacity and the payback period. For machinery cost evaluation, every piece of equipment is estimated in the table below.

Table 29. Cost evaluation of machinery

Position	Name	Cost, Eur.	Quantity, pcs.	Total cost, Eur.
Box folding	Homag Paqteq F-200	385 000	2	770 000
Packaging conveyor + lifting platforms	Homag CM-10	95 000	2	190 000
Automated panel insertion	Robot cell	61 000	8	488 000
Box closing	Homag Paqteq S-200	124 000	2	248 000
Unloading	Automated outfeed system	476 000	1	476 000
			Total	**2 172 000**

For evaluating the gains of the automated packaging line, a reference point is needed for comparison. In this case, fully manual packaging line is taken for consideration.

The analysed situation is based on one 8-hour shift. The period which will be evaluated is the 5-year period, as the initial requirement was that the payback must be reached within five years of the automated packaging line. Manual packaging line will contain 30 workers with capacity up to 5 boxes/min. These numbers are based on actual numbers from manual packaging line of SC "Freda", which was discussed previously. Evaluating other needed parameters, it is taken that the average selling price of an article is 15 Eur., OEE is 75 %, an average monthly salary of worker – 1500 Eur. The calculations are based on expected cash flows, with consideration of capacity and OEE and costs which include material cost – 70%, workers' salaries (*5% annual increase is estimated due to inflation and overall yearly increase of wages*), direct cost (*electricity, C. air, additional materials, maintenance, etc.*) – 6 %, indirect cost (*administration employees' salaries, other non-related expenses*) – 9 %. Total expenses sum-up all the costs that are mentioned above. Total expenses subtraction from revenue indicates profit.

Table 30. Expected loss-profit calculations with a manual packaging line

Year	Capacity, boxes/min	OEE	Revenue, Eur.	Material cost, Eur.	Salary expences, Eur.	Direct cost, Eur.	Indirect cost, Eur.	Interest, Eur.	Total expenses, Eur.	Profit, Eur.
1	4	60%	4 355 €	3 048 €	540 €	261 €	392 €	- €	4 241 €	113 €
2	4	70%	5 080 €	3 556 €	567 €	305 €	457 €	- €	4 885 €	195 €
3	4	75%	5 443 €	3 810 €	595 €	327 €	490 €	- €	5 222 €	221 €
4	5	70%	6 350 €	4 445 €	625 €	381 €	572 €	- €	6 023 €	327 €
5	5	75%	6 804 €	4 763 €	656 €	408 €	612 €	- €	6 440 €	364 €

Note: all money values are expressed in thousands

From Table 30, we can indicate that from year 1, 113 000 Eur. profit is reached. Because of increasing OEE and capacity, the profit margin increases from 3 % to 5 %, in the 5-year period. The profit values will be considered when calculating the payback of automated packaging line.

For calculating the loss-profit sheet for automated packaging line, the same 5-year period is considered when working in one 8-hour shift. The selling price of an article is taken the same – 15 Eur. However, because automated machine provided higher consistency, OEE value is raised up to 80 %.

When it comes to workers' salaries, the base point is increased to 1700 Eur/month, with the same 5 % annual gain due to inflation. While the expenses remain as previously, the values of direct and indirect costs are set to 10 % and 11 %, adequately. This is done to evaluate the expenses which are raised because of higher energy consumption and higher maintenance costs. Also, when considering the investment, which is need – 2 172 000 Eur., interest expenses are added, as the interest rate is 5 %. Additional column which is added in the loss-profit sheet is payback evaluation. It considers the profit which is gained with automated packaging line subtracting from the profit, which is reached with manual line. This shows the real added value, which is gained from implementing the automated system.

Table 31. Expected loss-profit calculations with an automated packaging line

Year	Capacity, boxes/min	OEE	Revenue, Eur.	Material cost, Eur.	Salary expences, Eur.	Direct cost, Eur.	Indirect cost, Eur.	Interest, Eur.	Total expenses, Eur.	Profit, Eur.	Payback, Eur.
1	18	45%	14 697 €	10 288 €	979 €	1 617 €	1 470 €	109 €	14 462 €	235 €	122 €
2	19	50%	17 237 €	12 066 €	1 028 €	1 896 €	1 724 €	109 €	16 822 €	415 €	341 €
3	20	60%	21 773 €	15 241 €	1 080 €	2 395 €	2 177 €	109 €	21 001 €	771 €	891 €
4	21	65%	24 767 €	17 337 €	1 134 €	2 724 €	2 477 €	109 €	23 780 €	987 €	1 551 €
5	22	75%	29 938 €	20 956 €	1 190 €	3 293 €	2 994 €	109 €	28 542 €	1 396 €	2 582 €

Note: all money values are expressed in thousands

It is estimated that at the beginning, the automated packaging line would be performing at a lower rate, because of technical or manufacturing load issues. The values of capacity and OEE are increased accordingly within few years period, which allows higher profit numbers. From Figure 73, we can determine that the payback period of the automated packaging line is 4,6 year, which satisfies the requirements.

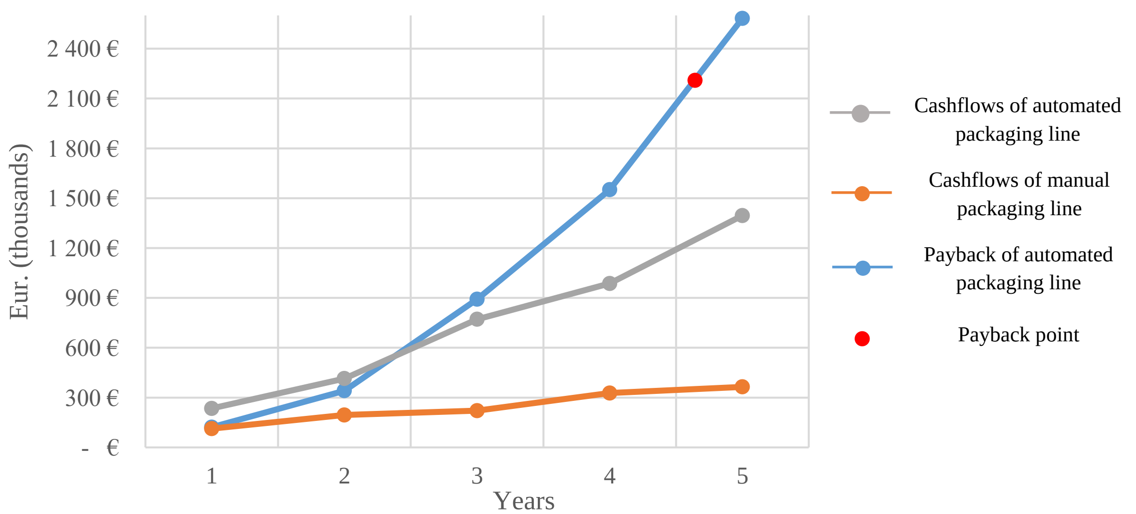


Fig. 73. Expected cash flow comparison between manual and automated packaging lines

Conclusions

1. **1.** Analysis of existing packaging lines in SC “Freda” and JSC “Baltic Furniture Components” showed what impact the automated system made on performance rate and profit. Implementation of semi-automated packaging line for SC “Freda” allowed to increase the packaging line’s capacity from 4 boxes/min up to 18 boxes/min. Which resulted in over 350% of increased profit. For JSC “Baltic Furniture Components” the decision of applying automated systems, provided an increase of capacity from 3,6 to 6 boxes/min, allowing the profit to grow by 66 %.
2. **2.** The designed packing line consists of two packaging conveyors that includes automated Homag Paqteq F-200 box folding (*Capacity 11,8 boxes/min*) and Homag Paqteq S-200 box closing (*Capacity 11,8 boxes/min*) machines, for each conveyor. The conveyor consists of total 26 work positions for object insertion into a box, from which 4 positions are replaced by the robot cells, for an automated panel insertion. The robot cell can perform up to 12 boxes/min. The two production flows are combined with the automated outfeed system. It contains transportation, sorting, overlap supply, pallet distribution and unloading tasks. The unloading task is carried out by a pair of robots which has a capacity up to 22,4 boxes/min. Though the automated outfeed system has a lower capacity than 23 boxes/min, buffer area within the system could allow to damp the stops and maintain needed performance. The designed packaging line fits in the designated hall and fulfils the requirement of transporting boxes directly the warehouse area.
3. **3.** The overall project has an estimated cost of 2 172 000 Eur. For the payback period evaluation, calculations were based on OEE of 75 %, an average article selling price of 15 Eur and one 8-hour shift. With these parameters, the packaging line could generate 235 000 Eur. profit, while a manual packaging line could reach up to 113 000 Eur. profit. These numbers would allow to reach the payback period in 4,6 years, which satisfies the requirements.

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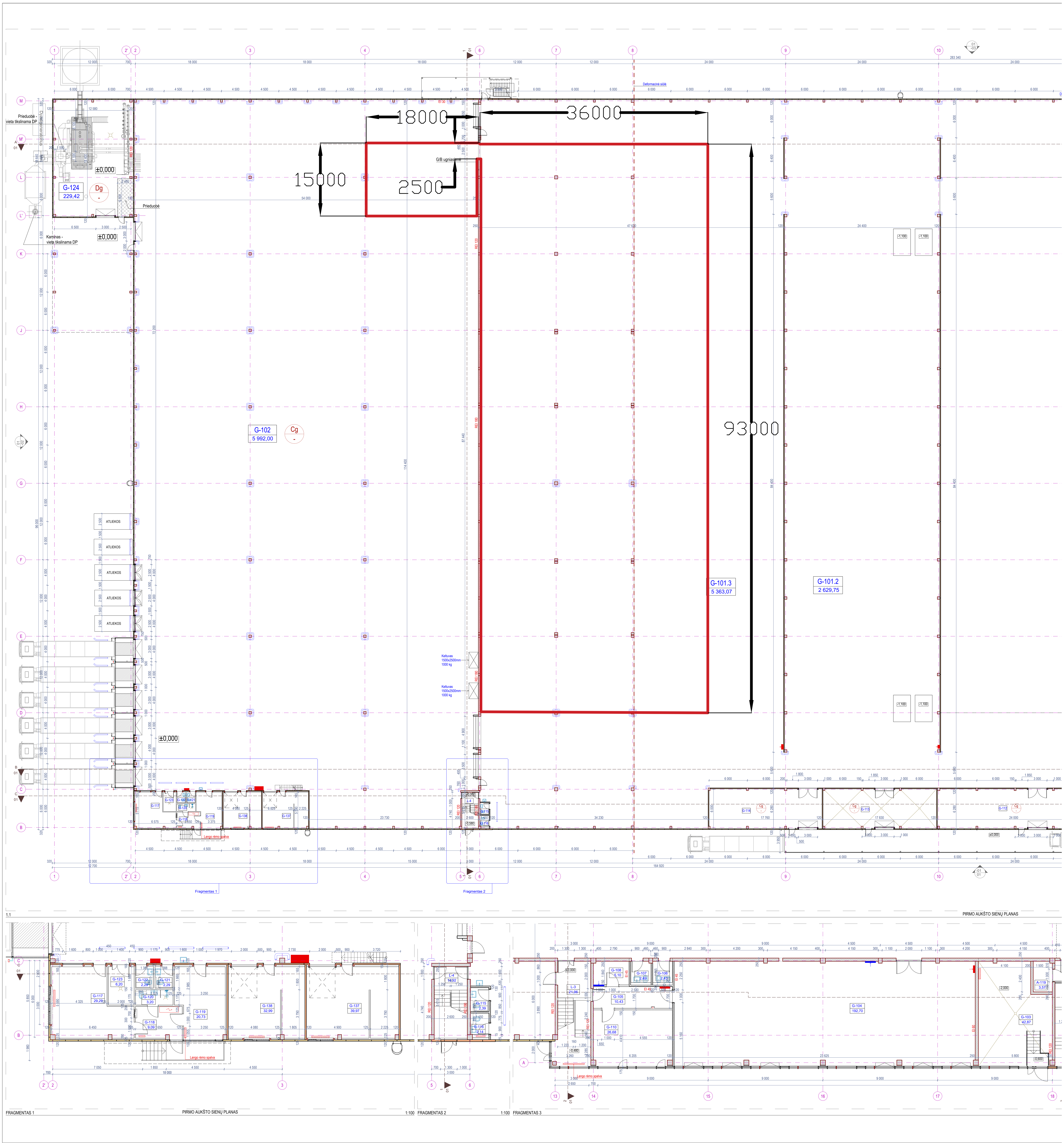
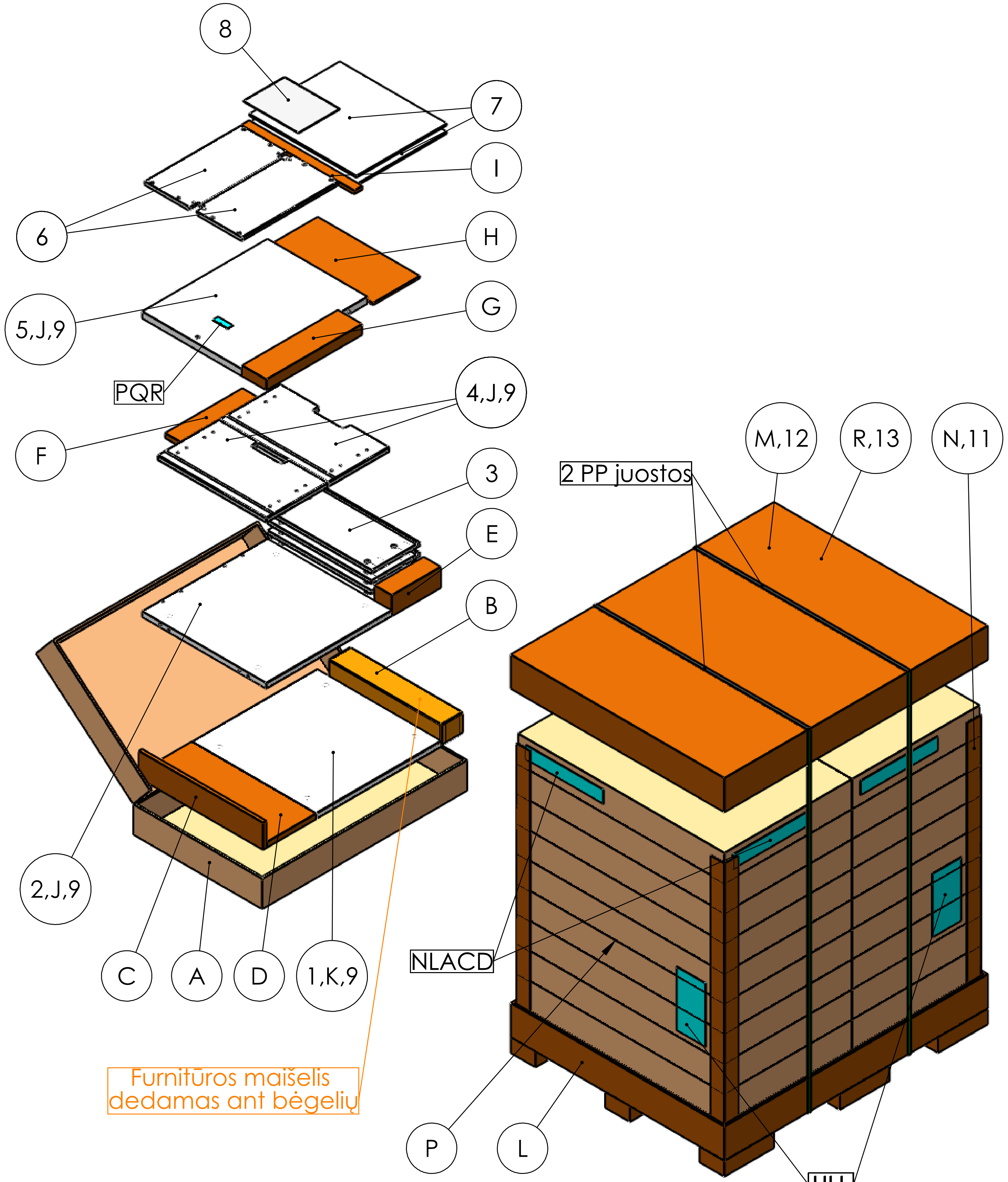
Appendices

Appendix 1. Drawing of designated hall for packaging line



Appendix 2. Drawing of article packaging arrangment

Keitimas	Data	Pastaba
1	2018.05.24	Korinio užpildo E - 178x66x66 mm matmuo pakeičiamas į 178x62x68 mm.



PAKAVIMO MEDŽIAGOS

PAKAS

A. GOFRAKARTONO DĖŽĖ, I 410
KOKYBĖ: IKEA CB 50, RUDA
VIDINIAI MATMENYS:
729 x 453 x 88 MM

B. GOFRAKARTONO DĖŽĖ FURNITŪRAI
KOKYBĖ: IKEA CB 30, RUDA
IŠORINIAI MATMENYS:
450 x 80 x 75 MM

C. KORYS-UŽPILDAS, IF 30
MATMENYS: 450 x 85 x 12 MM

D. KORYS-UŽPILDAS, IF 30
MATMENYS: 450 x 180 x 18 MM

E. KORYS-UŽPILDAS, IF 30
MATMENYS: 178 x 62 x 68 MM (1)

F. KORYS-UŽPILDAS, IF 10
MATMENYS: 280 x 55x 16 MM

G. KORYS-UŽPILDAS, IF 30
MATMENYS: 347 x 88 x 34 MM

H. GK-UŽPILDAS, IKEA CB 150
MATMENYS: 370 x 170x 7 MM

I. KORYS-UŽPILDAS, IF 30
MATMENYS: 410 x 30 x 12 MM

J. (x3) PUTINTA PLĖVELE APSAUGOTI SLUOKSNIAI
MATMENYS: 455 x 455 x 0,6

K. PUTINTA PLĖVELE APSAUGOTAS SLUOKSNIS
MATMENYS: 680 x 450 x 0,6

PALETĖ

L. POPIERINĖ PALETĖ (9 KOJELĖS)
KOKYBĖ: IKEA 230, RUDA
VIDINIAI MATMENYS:
940x 760 x 100 MM

M. VIRŠUJE PASTORINTAS GK LAKŠTAS
KOKYBĖ: IKEA 230, RUDA
MATMENYS: 940 x 760 x 100 MM

N. (x4) L-FORMOS KAMPŲ APSAUGA
MATMENYS: 910 x 50 x 50 MM

R. PALETĖS SUTVIRTINIMUI NAUDOJAMA:
* MAŠININĖ PAKAVIMO PLĖVELĖ
500 MM x 15 MKR
* (x2) PP JUOSTA 12mm x 0,8 mm

P. GK PERTIESIMAS, IKEA CB 30,
MATMENYS: 800 x 650 x 3 MM

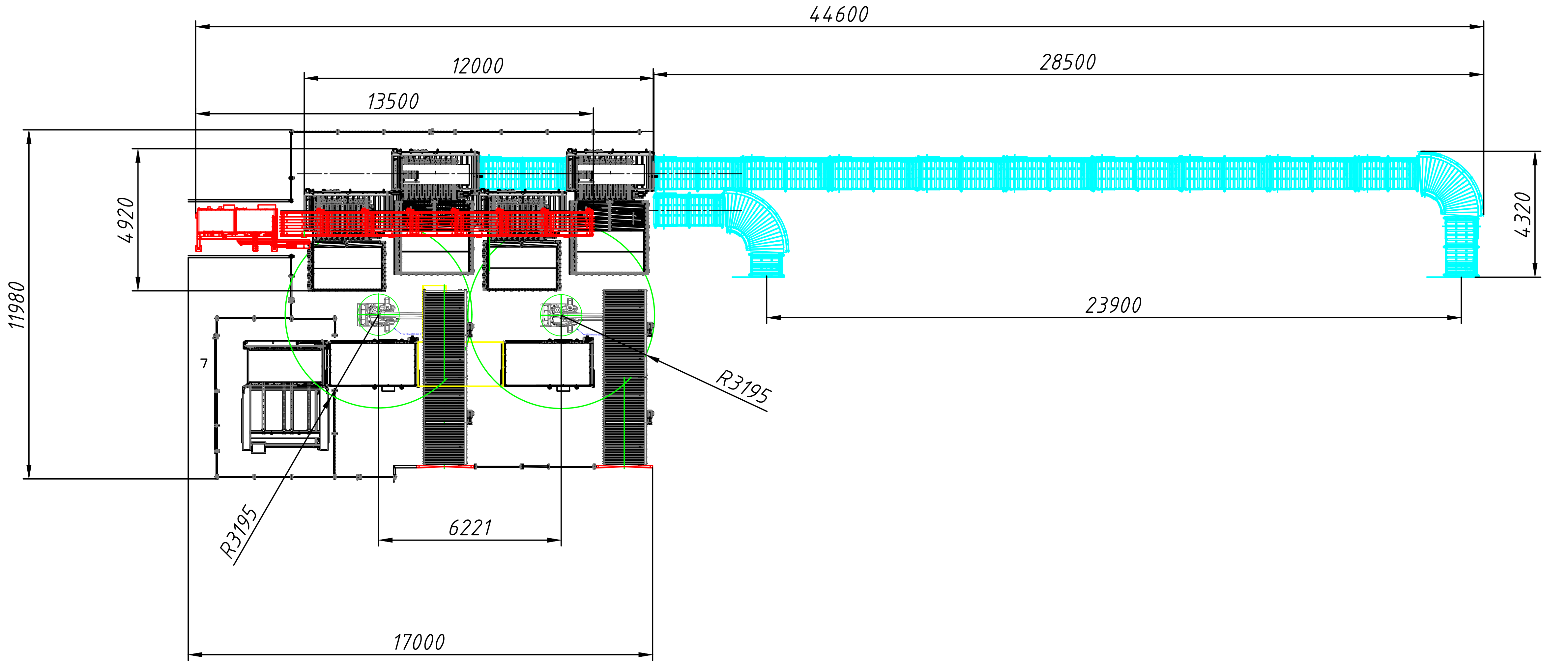
PAKAVIMAS

SUDĖJIMAS Į PAKĄ

1. ŠONINIS SKYDAS DEŠINĖS PUSĖS dažyta puse į viršų, FURNITŪROS DĖŽUTĖ, UŽPILDAI: C, D, E.
2. ŠONINIS SKYDAS KAIRĖS PUSĖS.
3. (x4) ST. PROFILIS universalus.
4. (x2) ST. PRIEKELIAI, UŽPILDAS F.
5. GALINIS SKYDAS (vidinėje pusėje, kur nėra lizdų, klijuojamas PQR lipdukas), UŽPILDAI G, H
6. (x2) ST. GALINĖ SIENELĖ,
7. (x2) ST. DUGNELIAI (A pav. į apačią), UŽPILDAS I.
8. SURINKIMO INSTRUKCIJA.
9. PUTINTĄ PLĖVELĘ TIESTI:
   1. (K) ANT ŠONINIO SK. DEŠINĖS P.,
   2. (J) ANT ŠONINIO SK. KAIRĖS P.,
   3. (J) ANT ST. PRIEKELIŲ,
   4. (J) ANT GALINIO SKYDO.

PALETĖ

Appendix 3. Layout of the automated outfeed system



File name	Additional information	Material	Scale 1:150
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	Approved by		Rev. A / Date 2020-05-17 / Lang. en / Sheet 1

Appendix 4. Cycle time calculation when working with one size dimension boxes

No	Description	Distance to travel, mm			Speed, ^{O}/s	Time, s
		x	y	z		
1	Home position	0	0	0	-	-
2	Pallet collection (C) waiting pos.	-900	-2650	+950	175 ^{O}/s	1,8
3	Pallet collection (C)	0	-50	0	175 ^{O}/s	0,1
4	Vacuum suction	0	0	0	-	0,15
5	Pallet collection (C) up pos.	0	+50	0	175 ^{O}/s	0,1
6	Pallet placement (D) waiting pos.	+500	+250	-950	175 ^{O}/s	1,5
7	Pallet placement (D)	0	-50	0	175 ^{O}/s	0,1
8	Vacuum release	0	0	0	-	0,1
9	Pallet placement (D) up pos.	0	+50	0	175 ^{O}/s	0,1
10	Box pick-up (A) waiting pos.	+1500	-2300	+1480	175 ^{O}/s	2,4
11	Box pick-up (A)	0	-50	0	175 ^{O}/s	0,1
12	Vacuum suction	0	0	0	-	0,15
13	Box pick-up (A) up pos.	0	+50	0	175 ^{O}/s	0,1
14	Box placement waiting pos.	-1900	-2150	-1480	175 ^{O}/s	2,4
15	Box placement pos.	0	-50	0	175 ^{O}/s	0,1
16	Vacuum release	0	0	0	-	0,1
17	Box placement up pos.	0	+50	0	175 ^{O}/s	0,1
18	Cardboard overlap (E) waiting pos.	+2400	-1250	+150	175 ^{O}/s	2,8
19	Cardboard overlap (E) collection pos.	0	-50	0	175 ^{O}/s	0,1
20	Vacuum suction	0	0	0	-	0,15
21	Cardboard overlap (E) up pos.	0	+50	0	175 ^{O}/s	0,1
22	Overlap placement waiting pos.	-1900	-2200	-1480	175 ^{O}/s	2,8
23	Overlap placement position	0	-50	0	175 ^{O}/s	0,1
24	Vacuum release	0	0	0	-	0,1
25	Overlap placement up pos.	0	+50	0	175 ^{O}/s	0,1
26	Box pick-up (B) waiting pos.	+1150	-450	+3400	175 ^{O}/s	2,5
27	Box pick-up (B)	0	-50	0	175 ^{O}/s	0,1
28	Vacuum suction	0	0	0	-	0,15
29	Box pick-up (B) up pos.	0	+50	0	175 ^{O}/s	0,1
30	Box placement waiting pos.	-1900	-2200	-1480	175 ^{O}/s	2,5
31	Box placement pos.	0	-50	0	175 ^{O}/s	0,1
32	Vacuum release	0	0	0	-	0,1
33	Box placement up pos.	0	-50	0	175 ^{O}/s	0,1
34	Cardboard overlap (E) waiting pos.	+2400	-1250	+150	175 ^{O}/s	2
35	Cardboard overlap (E) collection pos.	0	-50	0	175 ^{O}/s	0,1
36	Vacuum suction	0	0	0	-	0,15
37	Cardboard overlap (E) up pos.	0	+50	0	175 ^{O}/s	0,1
38	Overlap placement waiting pos.	-1900	-2200	-1480	175 ^{O}/s	2,1
39	Overlap placement position	0	-50	0	175 ^{O}/s	0,1
40	Vacuum release	0	0	0	-	0,1
41	Overlap placement up pos.	0	+50	0	175 ^{O}/s	0,1
42-116	Repeating movements of box and overlap placement	-	-	-	175 ^{O}/s	81,67
Total cycle time						107,75

Appendix 5. Cycle time calculation when working with two size dimension boxes

No	Description	Distance to travel, mm			Speed, ^{O}/s	Time, s
		x	y	z		
2	Pallet collection (C) waiting pos.	-900	-2650	+950	175 ^{O}/s	1,8
3	Pallet collection (C)	0	-50	0	175 ^{O}/s	0,1
4	Vacuum suction	0	0	0	-	0,15
5	Pallet collection (C) up pos.	0	+50	0	175 ^{O}/s	0,1
6	Pallet placement (D) waiting pos.	+500	+250	-950	175 ^{O}/s	1,5
7	Pallet placement (D)	0	-50	0	175 ^{O}/s	0,1
8	Vacuum release	0	0	0	-	0,1
9	Pallet placement (D) up pos.	0	+50	0	175 ^{O}/s	0,1
10	Box pick-up (A) waiting pos.	+1500	-2300	+1480	175 ^{O}/s	2,4
11	Box pick-up (A)	0	-50	0	175 ^{O}/s	0,1
12	Vacuum suction	0	0	0	-	0,15
13	Box pick-up (A) up pos.	0	+50	0	175 ^{O}/s	0,1
26	Box pick-up (B) waiting pos.	+1250	+550	+2870	175 ^{O}/s	2,5
27	Box pick-up (B)	0	-50	0	175 ^{O}/s	0,1
28	Vacuum suction	0	0	0	-	0,15
29	Box pick-up (B) up pos.	0	+50	0	175 ^{O}/s	0,1
30	Box placement waiting pos.	-1900	-2200	-1480	175 ^{O}/s	2,5
31	Box placement pos.	0	-50	0	175 ^{O}/s	0,1
32	Vacuum release	0	0	0	-	0,1
33	Box placement up pos.	0	-50	0	175 ^{O}/s	0,1
34	Cardboard overlap (E) waiting pos.	+2400	-1250	+150	175 ^{O}/s	2
35	Cardboard overlap (E) collection pos.	0	-50	0	175 ^{O}/s	0,1
36	Vacuum suction	0	0	0	-	0,15
37	Cardboard overlap (E) up pos.	0	+50	0	175 ^{O}/s	0,1
38	Overlap placement waiting pos.	-1900	-2200	-1480	175 ^{O}/s	2,1
39	Overlap placement position	0	-50	0	175 ^{O}/s	0,1
40	Vacuum release	0	0	0	-	0,1
41	Overlap placement up pos.	0	+50	0	175 ^{O}/s	0,1
42-172	Repeating movements of box and overlap placement	-	-	-	175 ^{O}/s	113,6
Total cycle time						130,7