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STEEL DOORS MANUFACTURING PROCESS ANALYSIS AND IMPROVEMENT IN METUS-EST AS

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Master's thesis task

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Student: *Vitali Tkatšuk, MARM 122166*

Field of study: *Industrial Engineering and Management*

Supervisor: *Research Scientist , Tatjana Karaulova*

Consultant(s): ……………………………………………....(name, position, phone)

Master's thesis topic (estonian and english languages):

Terasuste tootmisprotsessi analüüs ning täiustamine ettevõttes Metus-Est AS

Steel doors manufacturing process analysis and improvement in Metus-Est AS

Tasks and timeframe for their completion:

Nr	Task description	Completion date
1	*Initial data collection and preparation for the project*	*February*
2	*Time measurement, visual analysis of manufacturing process and documentation*	*March*
3	*Simulation analysis implementation*	*April*
4	*Steel doors manufacturing process improvement*	*April-May*
5	*Economical calculations implementation*	*May*

Engineering and economic problems to be solved:

Carry out steel doors manufacturing process simulation, figure out bottlenecks, offer methods for bottlenecks elimination and carry out economical calculations for project payback time.

Defence application submitted to deanery not later than: 18.05.2015 Deadline: 25.03.2015

Student: *Vitali Tkatšuk* /signature/ ………..…………. date: 25.05.2015

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FOREWORD

Given thesis topic was chosen according to a personal interest in steel doors manufacturing process improvement and eliminating of bottlenecks. Every day confronting with some issues in the workshop such as excessive accumulation of goods in the production area, overloaded machines and idle times that do not bring value to final product, gave an idea to connect thesis with streamlining the steel production workshop and improvement manufacturing process of producing steel doors.

In the framework of thesis was carried out simulation and analysis of existing production process and offered methods for eliminating the bottlenecks. Moreover, subsequent simulation and analysis of offered solutions were carried out. Economic calculations were also made in order to estimate profitability and payback time of project.

At the same time, I would like to express gratitude to my master thesis supervisor, Research Scientist of Tallinn University of Technology, Tatjana Karaulova, who was supporting me during thesis writing, giving advices and coordinating my activities.

1. INTRODUCTION

In recent years there are two closely related trends of economic development. On the one hand - this is globalization, which currently covers not only the traditional markets of goods, technology, capital and labour, but also management systems, support of innovation, development of human capital. Due to the continuous development of new and existing companies and increasing competition in the market, successful companies have always wanted and will seek to optimize the structure of the enterprise in terms of the minimum costs and improved services. In fact, the practice of enterprise management has developed a list of ways how to improve efficiency, including reduced costs, reforming the organizational structure, optimization of employment, stimulating investment activity.

It is obvious that market situation and preferences of end-users are constantly changing pushing the companies to match them. In any system, in all processes - from manufacturing to social services - there are hidden losses or operations that do not create value. Companies which know their processes, regularly assess their performance and improve organizational structure continuously, manage to save significant amount of capital and achieve customer satisfaction.

In the framework of current thesis, was offered to analyse and simulate existing steel doors manufacturing process using Enterprise Dynamics software, define problems in present process and offer methods for solving the goals presented below.

THESIS GOALS AND TASKS

The goals of thesis are:

- Achieve smooth production without delays or idles;
- Increase production throughput;
- Shorten production time;
- Improve process and quality of finished products;
- Reach better resource utilization.

The tasks of thesis are:

- Build-up manufacturing process flowchart;
- Carry out manufacturing process modelling and simulation;
- Analyse current production and identify bottlenecks;
- Offer solution for eliminating bottleneck and lead necessary calculations;
- Carry out new process modelling and simulation after process redevelopment;
- Analyse the results and improve manufacturing process;
- Carry out economical calculations of project payback time.

The software used in thesis:

- *AutoCad* – software application for 2D (3D) CAD design and drafting;
- *Kbk Stalprofil* – software for creating drawings, calculation of cuttings, packaging, cost of materials and manufacturing;
- *SmartDraw* – visual processor used to create flowcharts, organization charts, mind maps, project charts;
- *Enterprise Dynamics* – discrete event simulation software platform to design and implement simulation solutions.

2. OVERVIEW OF METUS-EST AS

2.1. History of Metus - Est AS

Metus-Est AS was founded in 1992 and began its operations in aluminum and steel profiles and glazed doors as a manufacturing and installing company. First company name was Metus-Metall AS, further it was renamed to Metus-Est. First customers
were local and in 1998 company received order from Latvian Airport. In 2000 first products were exported to near Scandinavian neighbour – Sweden. In 2007 Metus-Est AS bought its competitors – Fassaadimeistrid and in 2012 started unitized facade production.

Company belongs to the Estonia owners, who are also the founders of the company, and participate in the management and operation of the organization. For the moment, company has about 140 employees. Metus-Est AS has daughter companies, dealing with financial issues and accountancy and situated in Finland (Metus Finland OY, established in 2009), in Sweden (MetuSweden AB, established in 2011) and in Norway (Metus-Est As Inter Revisjon Consultancy AS). Metus-Est AS exports most of products to Scandinavian countries: Sweden, Finland and Norway. Moreover, products can be spotted not only everywhere in Estonia and Scandinavia, but also in Russia, Latvia, Lithuania, Germany and Portugal. Most valuable and complex orders were: Tallink SPA & Conference Hotel (Tallinn), ÅF-House (Göteborg), Malmö Citytunnel (Malmö), Tammsaare Business centre (Tallinn), Rica Hotell (Narvik), Norrströmstunnerln (Stockholm). [1]

Company strategic planning is built on next goals:

Mission

We offer manufacturing and installation of aluminium and steel profile glass elements for a reasonable price and a good quality in Estonia and Scandinavia.

Vision

To be a reliable and efficiently operating manufacturer and installer of aperture fillers that is recognized on the Estonian market and has strong partners in Scandinavia.

Goals

- Provide Scandinavian market with aluminium and steel profile glass doors at a reasonable price and a high quality;
- To be acknowledged as the complex design and reliable solutions providing company;
- To learn and progress continuously - we introduce new materials and test their suitability for buildings.

Goals for 2015

- Reach turnover of 20 million €
- Earn profit of 1 million €

Corporate values

- Cooperation

We apply the principle of equal partnership.

We set common goals and work in order to achieve them.

We ask for and offer help in case of need

We take and bear responsibility

We are motivated to participate in teamwork.

- Trust

We keep promises given to our clients, cooperation partners and colleagues.

We are open to other people's opinions.

We give and ask for feedback.

We say out what we think.

We notice and evaluate everybody's personal input.

Environmental liability

We fulfil the environmental requirements.

We are committed to reducing pollution.

We use environmental friendly technology.

- Balance

We evaluate our employees' leisure time.

We organize family and sports events.

We support a healthy life style.

- Orientation to development

We want to learn.

We learn from our own mistakes and those of others.

We are constantly improving our operation processes and technologies.

We develop ourselves as persons and team members.

We share our knowledge with team members.

- Giving our best

We use our working time efficiently.

Instead of ignoring the problems occurred, we look for their solutions.

We are not going to capitulate in case of difficulties.

We consider team’s interests to be higher than personal ones.

We offer our clients the best possible solutions.

We guarantee high quality even in case of complicated solutions. [1]

2.2. Metus - Est AS production

Production is based in Tabasalu on 18 Ranna Street in an approx 8000 m² facility.

- Aluminium profile products are manufactured on an area of approximately 4000 m².

Total 2 factories and 40 employees.

- Steel profile products are manufactured on an area of 2000 m².

Total one factory and 25 employees.

- Flashings factory has area of 1000 m²

Total one factory and 6 employees.

- Enclosed storage area is about 1000 m²

Total one warehouse and 2 employees.

Company offers a wide range of different solutions. Main categories are:

- Aluminium profile (doors, windows, curtain walls);

Doors are made from Schüco ADS 65, ADS 70.HI or ADS 75.SI profile systems.

Windors are made from Schüco AWS 65. AWS 70.HI or AWS 75.SI profile systems.

Curtain walls are made from Schüco FW50$^+$.SI, FW50$^+$.HI, FW50$^+$.1, FW50$^+$, FW50$^+$AOS, FW50$^+$SG, FW50$^+$BF profile systems.

- Steel profile (doors, windows, curtain walls);

Internal doors/windows are made from SP35000/SP55000/SP75000 profile systems.
External doors/ windows are made from SP56500/SP59000/SP511000 profile systems.
Fire resistant doors/ windows are made from SP35000/SP76500/SP79000 profile systems.

- Custom solutions (load point holders, glass columns);
- Unitized facade

Parts of the unitized facades are manufactured and pre-assembled at the factory before shipping to the site. The installation time is several time faster in comparisons to standard glass facade. Every unitized facade is unique and is designed according to customer needs. The external surface of the element can be made of different materials like: glass, metal sheet or other weatherproof materials. [1]

2.3. Metus - Est AS economic situation, its main competitors and partners

Biggest and strongest Metus-Est AS customers are:

- Skanska AB (multinational construction and development company based in Sweden);
- Peab AB (construction and civil engineering company headquartered in Sweden);
- NCC AB (Swedish construction company);
- YIT Rakennus Oy (Finnish construction company). [2]

The most valuable partners are:

- Ruukki
- Assa / Abloy
- Forster
- Jansen
- Stålprofil
- Schüco
- Sapa
- Dorma
- DSE
- Transpoint

Main competitors are:

- AS Saku Metall
- T-Tammer
- Windoor AS
- Metek profiil
- Metek alumiinium
- Malmerk
- Ekomet
- Aluver tootmine
- Terastehnika [2]

Metus-Est AS has a very strong financial position. All the key indicators are positive, and must provide the security of any communication with partners. According to the turnover analysis presented in *Figure 1* for the year 2012-2013, the turnover for the last year increased by almost 4 million euros. Comparing to its closest competitors showing a very positive result. But on the other hand, profit has decreased (see *Figure 2*). The reason was in complex projects, time frames, flow of workers. [2]

Metus-Est AS continues to develop and expand its market share in Estonia and Scandinavia. According to Metus-Est AS turnover distribution chart (see *Figure 3*), a large share of turnover takes place in Swedish market (61%), smaller part belongs to Finnish and Estonian market, 22% and 16% respectively. [2]

Less turnover takes in Norway, because for Metus-Est AS it is fairly new, only developing and growing relationship. Essentially, the Norwegian market for the Metus company is at the same stage as the Sweden and Finland used to be in 2007 - company is present in the market, the work is carried out, but a significant presence does not exist yet. Nevertheless, contacts and partners are being induced and in near time it is planned to increase the share of turnover attributable to the Norwegian market. In fact, Metus-Est AS is planning to reach reach turnover of 20 million € and earn profit of 1 million € during the year 2015. At the moment, the forecast is feasible provided that the work will be done in the same vein and costs, which do not bring value, will be eliminated.

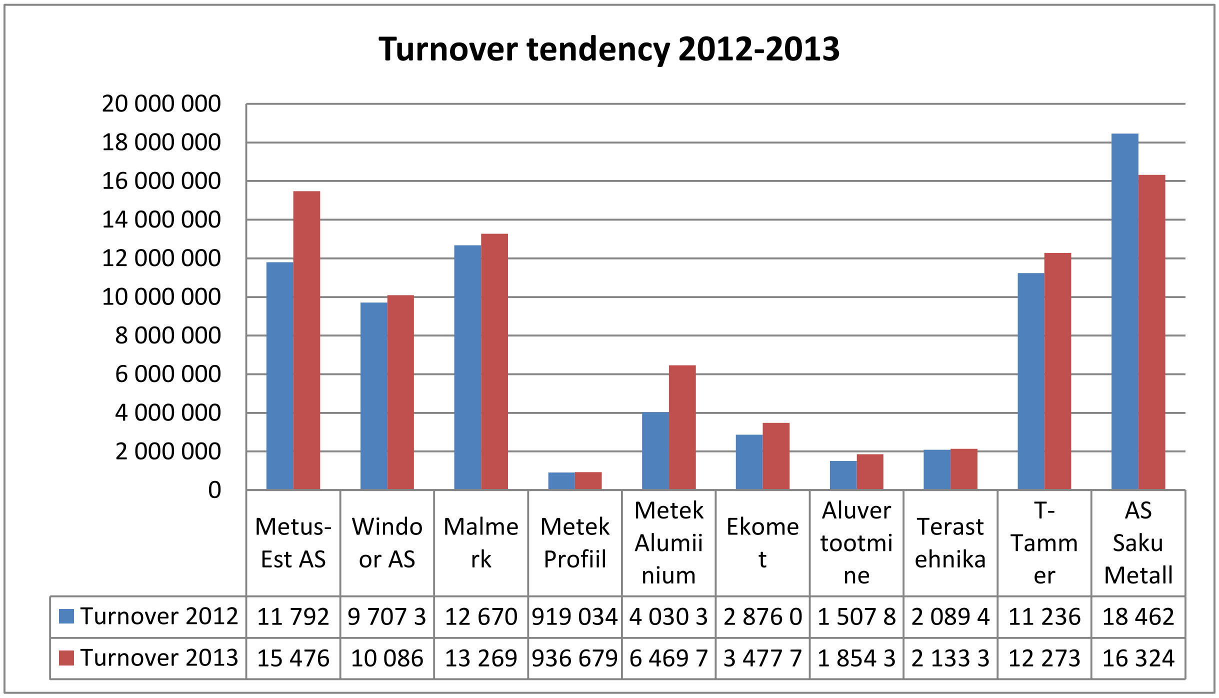


Figure 1.Turnover tendency 2012-2013

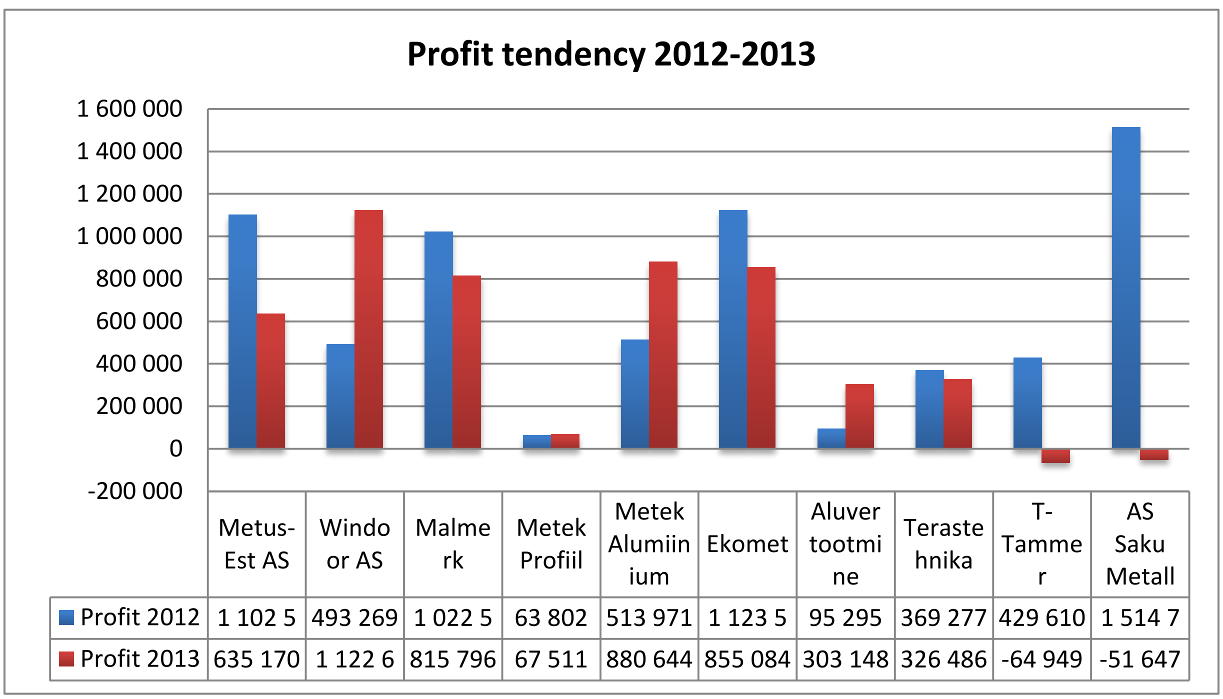


Figure 2. Profit tendency 2012-2013

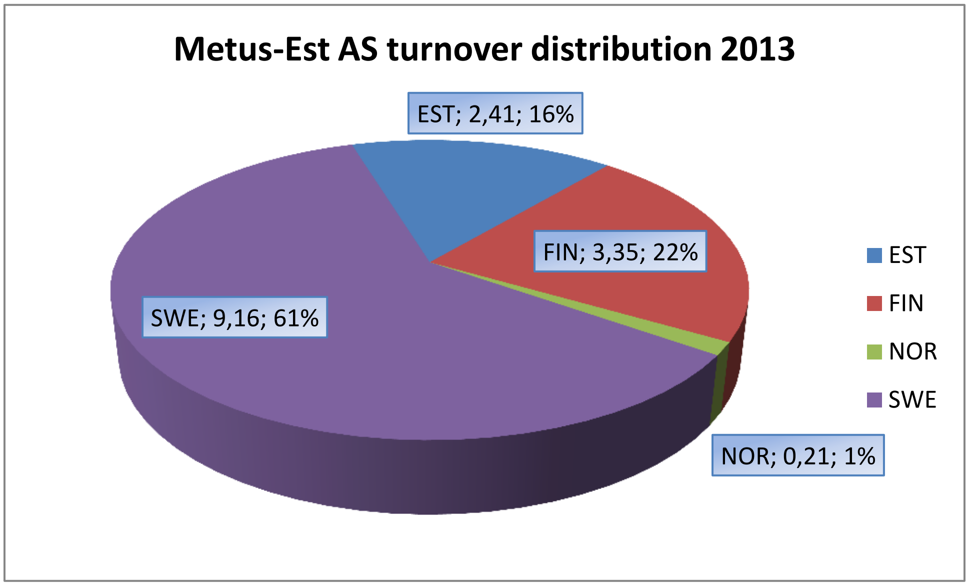


Figure 3. Metus-Est AS turnover distribution 2013

2.4. Metus-Est AS SWOT analysis

SWOT analysis (Strengths - Weaknesses - Opportunities - Threats) is a methodology that describes the company's strengths, weaknesses, opportunities and threats in the external and internal environment. Completed SWOT analysis provides an overview of developments in the company, taking into consideration the potential risks.

Strengths

- Effective structure;
- Stable staff;
- Good teamwork;
- Presence of technical competence;
- Internal quality control;
- Providing complex solutions;
- Flexibility in making special solutions;
- Full service providing company.

Weaknesses

- Information flow from one department to another sometimes creates difficulties;
- Excessive flexibility, meaning that company also allows solutions, which is difficult to perform;
- Distances to export markets.

Opportunities

- Access to new markets and across all regions;
- The price pressure will force foreign countries to reject from “local" preference;
- Finnish-Swedish competitors prefer to make a mass product, Metus-Est AS is project-based company;
- Good reputation.

Threats

- Further reduction in the construction market;
- The raw material price increment;
- Foreign trade unions processing of setting fees;
- Finland, Sweden bureaucracy contracts (insurance, tax authorities, reports, supplies across the border);
- SEK exchange rate fluctuations. [3]

The company's significant strengths are coming from its structure and the experience developed in the provision of services. Working for the will to perform a more sophisticated solutions, has given the opportunity to learn and to ask for a higher cost. At the moment, there is a very good awareness of the denomination of the target markets; also the production capacity and efficiency have been significantly improved. Thus, the company is able to take a new step to grow sales in the target countries.

2.5. Product development

The company's product development is divided into two parts:

a) Innovative solutions providing

The company works closely with suppliers to develop innovative materials and solutions. For example, development of methods for reduction of the thermal conductivity, that helps to bring to a minimum energy losses. Also, constantly are developing new ways of glass elements fixing solutions.

b) Internal product development

Every important building facades are manufactured for the essence of a product development - all products are manufactured with precision fit for the building, develop engineering solutions to ensure permanence and durability of the facade.

In-house product development and innovative solution providing ensures the competitiveness of the company. [4]

Metus-Est AS is currently satisfied with the range of products offering. Compared to competitors, company has wide range of unique products; usually, building companies only a few products (glass columns, single point fixing facades, wire rope fittings facades, roof windows etc.). The company's product range also confirms the competitiveness of the turnover, of which approximately one-third have come from foreign countries.

In services development field, growing emphasis is on the provision of full service. Some years ago, the full service of aluminium elements was offered in approximately of 60% cases, but lately given number has been growing rapidly and now the number has reached the 98%, meaning that practically in all cases full service is being provided. Moreover, changes have affected the steel elements also. The number has grown from 25% to 65%. Full service is attractive because it allows asking for a higher cost and it is also possible to guarantee the quality of installation and durability of structures. [4]

2.6. Production and service processes

Metus-Est AS production process depends on the type of product made. Company position is to be manufacturing and service providing company at a high variety of products and a low volume. Thus, manufacturing process type is project based and service process type is professional, when every product is unique and is manufactured according to customer needs and wishes. Manufacturing process is built on make-to-order concept, when production starts when customer order received. Supply chain operations process is pull-type, because manufacturing starts only when actual demand is prescribed by customer. [5]

Material delivery time takes 1-5 weeks. Longer delivery time is needed for the fittings that come from the manufacturer's country; in average delivery takes 1-2 weeks. Metus-Est As does not have warehouse for finished goods or much space for raw materials (total of $400m^2$ of warehouse area is available). Huge role in logistics plays reliable suppliers, who can provide on-time delivery of necessary items. However, the most widely used steel materials and fittings are kept in stock to satisfy approximately one month of demand. Aluminium and glass stock is not kept, because configuration of them is strictly depending on project itself.

Production, according to incoterms, can be shipped in two ways. First way is Ex Works, when the customer comes for the finished goods personally; the seller's obligations do not include export customs clearance. The second case is Delivered Duty Unpaid, when the goods are being shipped directly to a customer’s named place; customer pays for transportation, custom clearance. One truck is able to carry 200 m^2 section of the facade. The installation can be performer by Metus-Est AS own team members or subcontractors. [4]

2.7. Production overview

The company's production capacity is difficult to bring out. The reason is in the difference of projects. In case all the products were pretty similar to each other, with the solution, then it would have been easier to lead calculations and estimations. However, complex products require more preparation time and depending on project, it is completely different. It is also difficult to bring out the product units - tons of output, m^2 of profiles, etc.

In fact, Metus-Est AS does not lead any statistics about how many elements and what products are produced in a period of time. In order to make any analysis and improvements in future, in was decided to analyse the number of sales for year 2014 with the aim to bring out more popular range of products and further to choose the most popular one. In the statistical analysis were considered only steel elements, because the further production analysis and improvements are going to be done directly in steel manufacturing workshop and will affect steel element production process.

In the year 2014, all the steel elements were produced on the basis of two different profile systems. First one is the Swedish profile system – Stålprofil and the second one is Finnish profile system Jansen. Every profile system has many types of different subsystems, depending on the purposes and conditions where future element is going to be exploited.

For the year 2014 those subsystems were (see *Figure 4*):

- Jansen (Janisol, Janisol 2 EI30, Janisol 2 EI60, Economy 50)
- Stålprofil (SP 35000, SP56500, SP76500, SP79000, SP95000, SP77000, SP957000) [4]

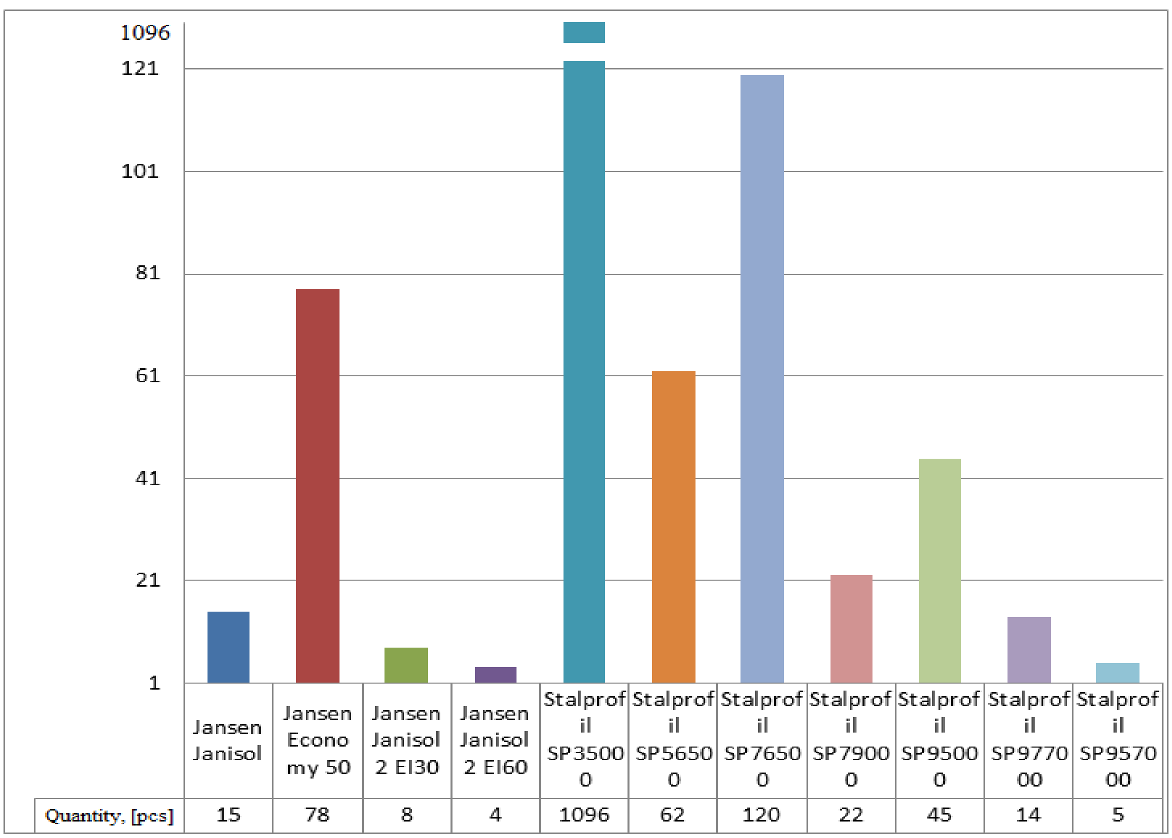


Figure 4. Metus-Est AS steel elements sales chart 2014

As it became clear, among the Jansen profile systems, leader turned out to be Jansen Economy 50 (78 steel elements) and the leader among Stålprofil became SP 35000 (1096 steel elements). Usually there is no such a huge difference in the results. In fact, the reason for this was a big project with a total amount of all elements 3000 pieces. Thus, it turns out that the main doors were required SP 35000 profile system. Below there will be shown the main differences of those profile systems and conditions where the elements can be used.

2.8. Main categories of steel doors

The most common category of steel doors, Metus-Est AS manufactures, can be represented by the following scheme (see *Figure 5*).

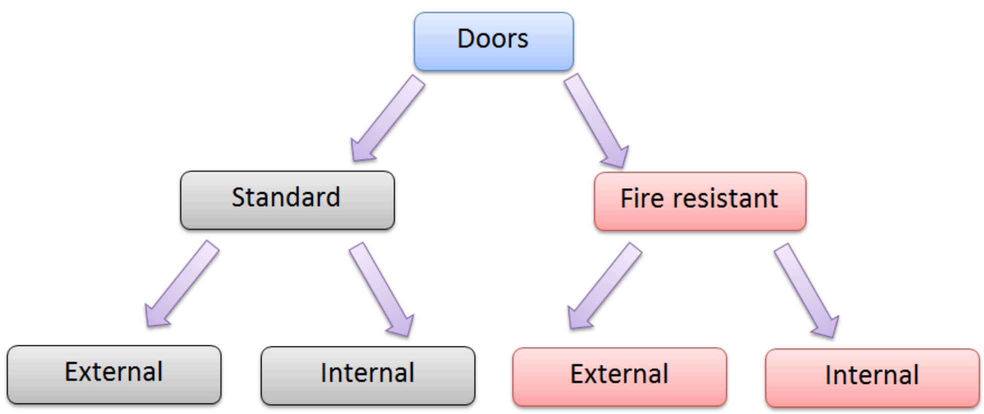


Figure 5. Classification of the most common steel doors

Basically, there are many different types of doors. The simplest is standard, which does not have any special requirements. As a special requirement can be fire resistance, smoke resistance, burglary resistance, bulletproof and radiation protection, etc. Directly in Metus-Est As, the most frequently ordered door types are standard and fire resistant. These categories are further divided into two subcategories: external and internal, depending on the conditions, where the doors are going to be exploited.

The most appropriate would be to compare the standard internal doors with fire resistant internal doors and the external doors the same way with each other respectively. For comparative analysis, profile systems are chosen according to the chart on *Figure 4*. For simplicity, we take two profile systems, SP 35000 and SP 76500 that cover all conditions shown in *Figure 5.*

We do not review Jansen profile system, because the principle solution and logic stays the same, only the structure is insignificantly distinctive.

2.9. Internal doors SP 35000 overview

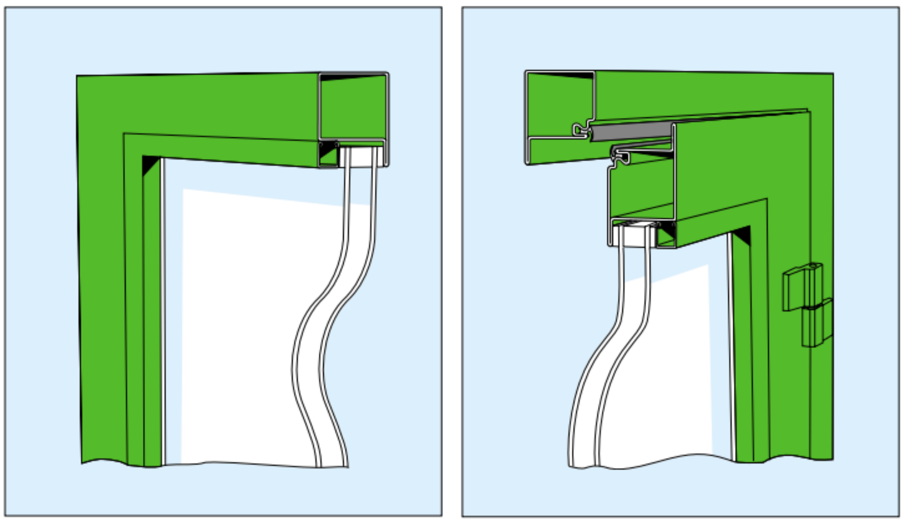


Figure 6. SP 35000 internal door section's 3d model [7]

Profile system SP 35000 is non-insulated steel profile solution. It has a breached thermal bridge, meaning that section of door joint has a low thermal resistance. Also it can be parts between the structural elements consisting of a material with high thermal conductivity. Such areas are cooled more than other parts of the fence, so they are called "cold bridges" or thermal bridges. Moreover, thermal bridges cause the condensation effect.

Given profile system is suitable for swing and sliding doors, wall or window sections. It can be used in offices, flats, hospitals, hotels, homes, schools areas. The profile system is also available in wide profiles, designed for modular locks and special features. The main advantage of SP 35000 is that it is a universal system, suitable for normal exploitation and fire resistant conditions. Moreover, it is also applicable in burglary resistant conditions. Bullet proof solution is also available. The systems has appropriate design and shape with special tracks for rubber sealing that creates smooth interior and exterior surfaces on doors wall partitions, that complies with architectural requirements. Stålprofil offers profiles in three different materials: untreated steel quality SS 1312, stainless steel quality 316L. Stainless steel profiles are also available in brushed or untreated. The third choice is sendzimir zinc galvanised profile (form of hot dipped galvanisation). SP 35000 profile systems are available for different shapes, like arches, rounded windows or arched doors. Round profiles have similar features and characteristics as standard straight parts. [7]

To sum up, SP 35000 is applicable to standard swing doors, windows, wall sections or sliding doors in both conditions, whether fire resistance requirements are imposed or not. It is the most popular and widely spread profile system in Sweden; most of the internal doors are made of given profiles.

2.9.1. Internal elements design overview

Below there are shown two internal door sections (see *Figure 7* and *Figure 8*) that are made of one type of profile system, one of which is standard door, and the other refers to fire resistant. Moreover, main parameters of these doors are presented in *Table 1* below.

Table 1. SP 35000 standard and fire resistant door comparison

Features	**Figure**	
	7	**8**
Element type	Internal	Internal
Profile system	SP 35000	SP 35000
Fire resistance class	-	EI 30
Environmental class	C1	C1
Glass	44.2 lam	Contraflam EI30-16
Glazing bead	SP 43020	SP 42520
Glazing band	EPDM	Kerafix
Top sealant	-	fireproof silicone
Glass support	plastic support	fireproof support
Glazing gap	8 mm	5 mm
Threshold	tube 40x20x2	tube 40x20x2

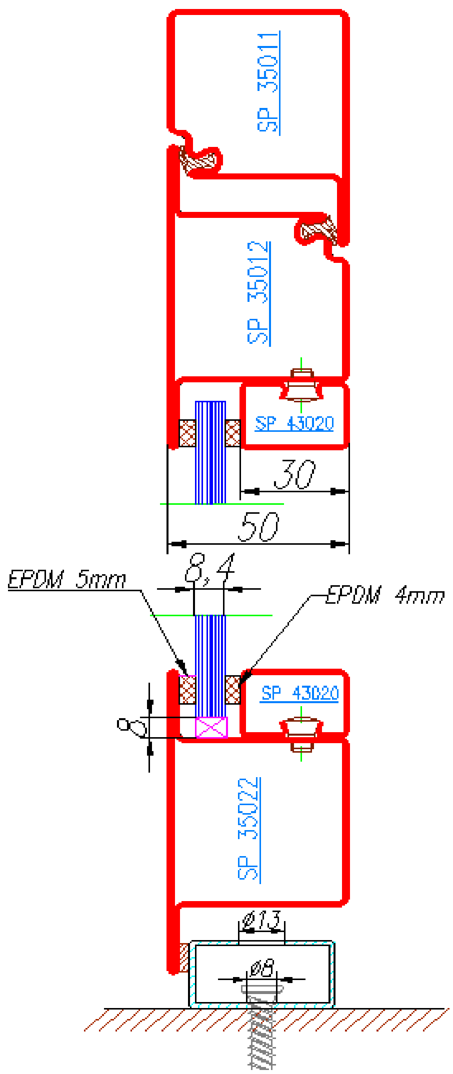


Figure 7. Standard internal door section

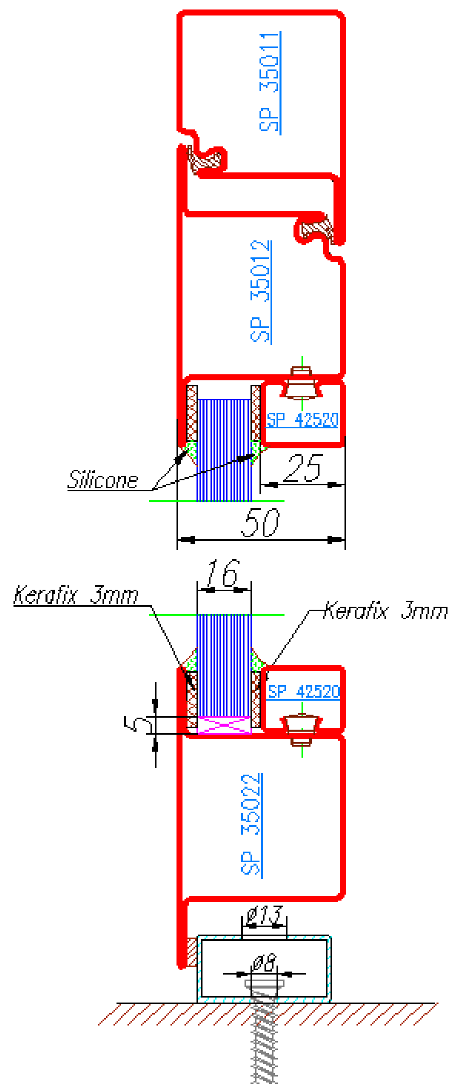


Figure 8. Fire resistant internal door section

The sections above describe two different solutions: *Figure 7* stands for standard internal door solution and *Figure 8* is typical solution for internal doors, but in case fire resistance features are required. Doors have some main features and some constructive differences also. For, example, a common feature is that both doors are made of the same profile system – SP 35000.

Moreover, both door are designed for internal conditions, thus, the environmental class is the same, C1. Environmental class shows the corrosion protection level of element (see *Table 2*). In case of internal conditions, no corrosion coating is required. Elements should be situated in a warm dry buildings with neutral atmospheres, were no fear of corrosion and the structural stability of the building will not be threatened during its design life (generally taken as 50 years). As an example of such places can be hospitals, schools, shops, hotels, etc.

One more common feature in given particular case is threshold type and dimensions. According to fireproof type approval it is allowed to use standard rectangular tube as a threshold, the same rule is valid to standard doors, which can be designed even without any threshold.

Table 2. Corrosion protection categories and example of typical environments [8]

Corrosivity category and risk	Low-carbon steel Thickness loss (μm)[a]	Examples of typical environments in a temperate climate (informative only)	
		Exterior	Interior
C1 very low	≤ 1.3	-	Heated buildings with clean atmospheres, e.g. offices, shops, schools, hotels
C2 low	> 1.3 to 25	Atmospheres with low level of pollution Mostly rural areas	Unheated buildings where condensation may occur, e.g. depots, sports halls
C3 medium	> 25 to 50	Urban and industrial atmospheres, moderate sulphur dioxide pollution Coastal area with low salinity	Production rooms with high humidity and some air pollution e.g. food-processing plants, laundries, breweries, dairies
C4 high	> 50 to 80	Industrial areas and coastal areas with moderate salinity	Chemical plants, swimming pools, coastal, ship and boatyards
C5-I very high (industrial)	> 80 to 200	Industrial areas with high humidity and aggressive atmosphere	Buildings or areas with almost permanent condensation and high pollution
C5-M very high (marine)	> 80 to 200	Coastal and offshore areas with high salinity	Buildings or areas with almost permanent condensation and high pollution

The main difference is that one door has fire resistance class EI 30 and the second one does not have. EI fire resistance class means that elements must be able to prevent the passage of flames and to block the heat transfer through the element within 30 minutes (see *Table 3*). There are also other fire resistance classes types like E and EW (see *Figure 9*).

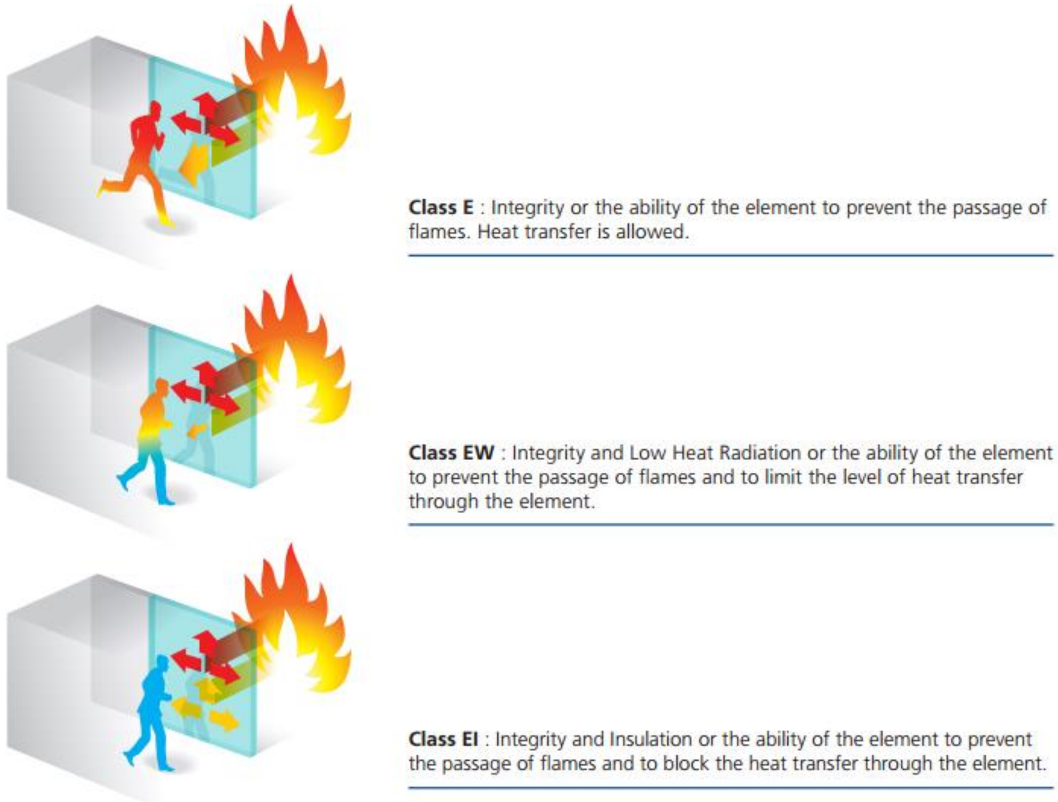


Figure 9. Fire resistance classes [9]

Table 3. Fire protection ratings according to EN 13501-2 [9]

Class/Duration	15 min	20 min	30 min	45 min	60 min	90 min	120 min
E	-	E20	E30	-	E60	E90	E120
EW	-	EW20	EW30	-	EW60	EW90	EW120
EI	EI15	EI20	EI30	EI45	EI60	EI90	EI120

The next difference is in glass type. For standard door is used 44.2 laminated glass. In this case glass panels are glued together to a layer of polymer film that is located between the panes. By using heat and pressure, air bubbles are removed from the laminate to obtain good optical performance. 44.2 is that consists of two 4mm panes of glass with a double PVB interlayer films, each 0,38 mm thick. In case of hit, laminated glass shards are held together due to interlayer films, which reduce the likelihood of injury. For example, windscreens cars are also made of laminated glass.

Fire protection door has to be equipped with special fire resistant glass. In this case, the glass is contraflam EI 30-16. Contraflam EI 30-16 is a fire resistant glass which consists of two sheets of toughened safety glass. The space between the sheets of glass is filled with a transparent intumescent gel interlayer which reacts when exposed to fire. In case of fire, the opaque expands to form a fully insulating heat shield. This reduces the transmission of radiated and conducted heat for up to 30 minutes. The opaque insulating interlayer blocks the view of the fire which minimises panic and acts as a guide for emergency services to indicate the presence of fire. [10]

Less significant difference is glazing bead size. It is obvious, because the glass thickness is different, thus the glazing bead is being selected accordingly. Glazing band type also plays huge role. Standard door is equipped with EPDM gasket (ethylene propylene diene monomer). Gasket is created on the basis of foam rubber, which has excellent performance characteristics, high strength and durability. Fire resistance doors, on the contrary, uses fire prevention gaskets – kerafix. It is made of flexible fire protection material with embedded intumescent components. In case of fire, when the temperature is rising, the material expands and forms a heat-insulating layer with low density that fills construction-related residual openings and expands over the cut edges. In order to increase the fire protection, it is required to seal the abutting corner joints of glass with steel elements with fireproof silicone. Internal standard doors do not have to be sealed at all. In fact, glass supports are also different, in case of standard door, the support can be made of plastic and is ordered according to glass width. Fire resistant doors are equipped with special fire resistant glass support according to stålprofil type approval and is selected in accordance to glass width. Thus glazing gap is also different, fire resistant door has 3mm less glazing gap for glass installation; it equals to 5mm on perimeter.

2.10. External doors SP 76500 overview

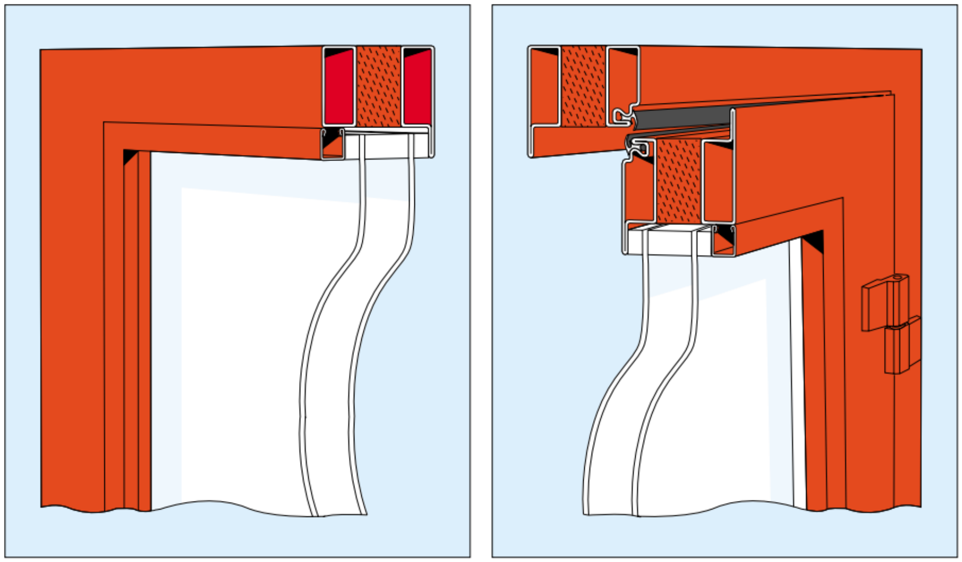


Figure 10. SP 765000 external door section's 3d model [7]

Profile system SP 76500 is insulated steel profile solution. The main advantage that it does not have thermal bridge, meaning that section of door joint has a good thermal resistance. Profile systems does not have condensation effect that can be caused by thermal bridges. That is why SP 76500 main applications are in external conditions.

SP 765000 can be used in different places, where thermal resistance is required. Such places could be shopping centres, airports, schools, hospitals, banks. Basically the same places as for SP 35000 systems, but in external conditions. Profile system is applicable to swing doors, sliding doors, windows and wall sections. The system is flexible and stable in different forms and shapes. It is also available in arch shape, for rounded wall sections or windows. [7]

The system is available for different special conditions: fire resistance, bullet resistance, smoke resistance, and burglary or noise protection. In fact, SP 76500 can be used in internal conditions also, in case, additional noise reduction or x-ray radiation protection is demanded. In that case it is needed to use thicker glass, thus the thicker profile system is needed for that. [7]

Profile system structure allows to block fire spreading and reduces the heat transfer from the fire side to opposite, making evacuation of people safe for a certain period of time (depending on fire class demand). [7]

SP 76500 is available in untreated steel quality SS1312 and allows much freedom of surface choice. Moreover, system is available in stainless steel quality 316L. The surface treatment offered in brushed or untreated conditions. Profile system is also available in sendzmir zinc quality, like SP 35000 systems. [7]

To sum up, SP 76500 is applicable for different conditions and mostly in an external condition, but, if required, can be used in internal also. It is also very popular profile system in Sweden, the same popular as SP 35000. As it is clear, one of them is designed for internal conditions, the second one – for external.

2.10.1. External elements design overview

Below there are shown two external door sections (see *Figure 11* and *Figure 12*) that are made of one type of profile system, one of which is standard door, and the other refers to fire resistant. Moreover, summary table (see *Table 4*) with the main parameters and differences is brought out for easier visual comparison.

Table 4. SP 35000 standard and fire resistant door comparison

Features	**Figure**	
	11	**12**
Element type	External	External
Profile system	SP 76500	SP 76500
Fire resistance class	-	EI 30
Environmental class	C3	C3
Glass	44.2+44.2-9Ar	Contraflam EI30-16
Glazing bead	SP 42520	SP 44020
Glazing band	EPDM	Kerafix
Top sealant	standard silicone	fireproof silicone
Glass support	plastic support	fireproof support
Glazing gap	8 mm	5 mm
Threshold	tube 50x20x2	tube 50x20x2

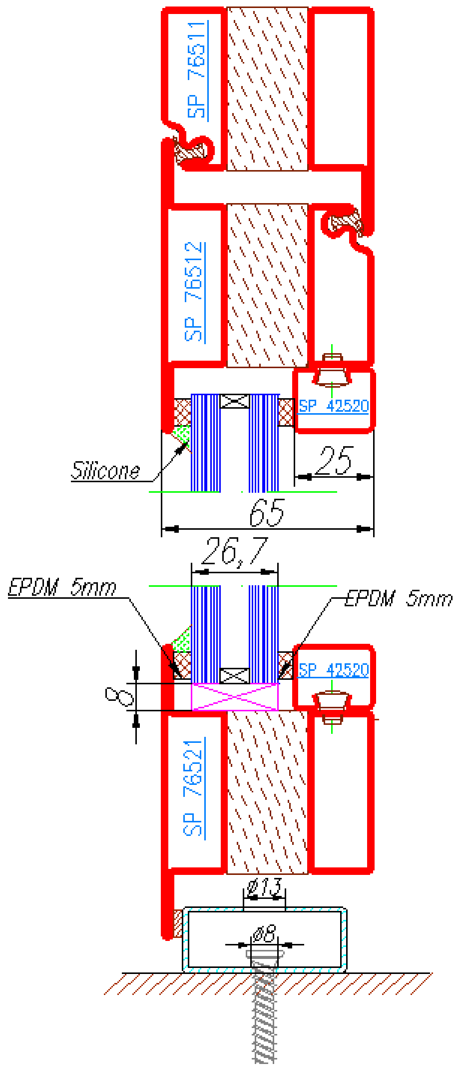


Figure 11. Standard external door section

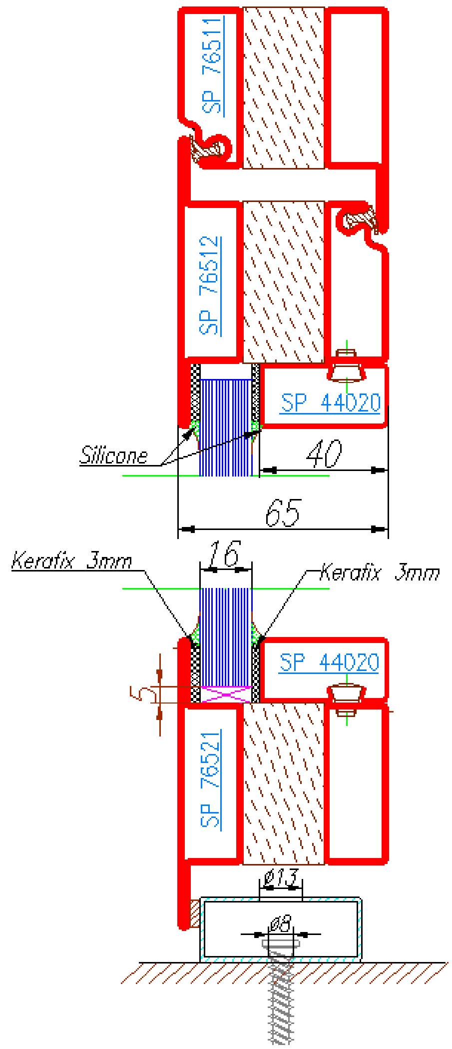


Figure 12. Fire resistant external door section

The sections above describe two different solutions: *Figure 11* stands for standard external door solution and *Figure 12* is typical solution for external doors, but in case fire resistance features are required. Doors have some main features and some constructive differences also. First common feature is that both of the doors are made of the same profile system – SP76500. In addition to that, both doors are designed for external conditions, meaning that the environmental class is the same also, C3 (see *Table 2*). According to ISO 12944, C3 class can be applied for internal production buildings with high atmospheric humidity, places like: breweries, laundries, food manufactures, etc. Also C3 is suitable for external conditions, for areas with sulphur dioxide pollution, coastal areas with low salt content, urban and industrial areas.

Another common feature is the threshold, for both cases it is 50x20x2 mm tube that is suitable for standard and fire protection doors. In both cases tubes are made of stainless steel, because of exploitation in external conditions.

The main difference is that one door has fire resistance class EI 30 and the second one does not have are fire resistance requirements at all. For additional information what does EI 30 stands for see *Figure 9* above.

One more difference is in glass type. Standard door has insulated glazing solution 44.2+44.2-9Ar. It is double glazing glass panel with two laminated panels. Glass panels are glued together to a layer of polymer film that is located between the panes. 44.2 consists of two 4mm panes of glass with a double PVB interlayer films, each 0,38 mm thick. Both panels are separated by argon gas that is filled the space in order to reduce heat transfer across a part of the building envelope. On the other hand, a fire protection door has a fire resistance glass - Contraflam EI 30-16 that reduces transmission of radiated and conducted heat for up to 30 minutes.

The width of glazing beads on both elements is also different, because of the different glass thicknesses, but the type of bead is the same. Glazing band type is selected according to the same logic as for internal elements. Fire protection elements have to be equipped with special fireproof gaskets, type Kerafix. Standard door has EPDM rubber gaskets across the glazing side.

The sealing has to be carried out on both elements. EI 30 door has fireproof silicone on the both sides of glass and standard door has to be sealed also, but with standard silicone and only on external side, which contacts with external environment.

Fire protection doors are equipped with fireproof glazing supports, that are 5mm high and standard door has 8 mm plastic supports.

2.11. Summary

Taking into consideration, steel elements sales chart for year 2014 (see *Figure 4*), the most popular element's subsystem is SP 35000 referring to Stålprofil profile manufacturer. However, there are two different possibilities: to produce standard door or fire resistant. Due to the fact, that production process of both door types is pretty the same, we consider that further process improvements are going to be carried out with fire resistant door type.

Basically, the process steps are similar in both cases, only some additional regulations are required to provide to get fire resistant element. In addition, there are no so serious differences between internal and external standard elements. It is more about the designer's work, because they need to properly assign solutions, control whether the different types of fittings can be worked together in order to meet the customer's desires providing that solutions do not contradict the decisions prescribed in catalogs and certificates. Directly, the production process sequence and steps remain the same in both cases.

To sum up, as an example will serve the door, that is the most frequently occurred in production, the fire resistant internal door SP 35000. Given door is presented below (see *Figure 13*).

Figure 13. SP 35000 fire resistant internal door

3. MANUFACTURING OF STEEL DOORS

3.1. Manufacturing process overview

The main manufacturing process goals are:

- Meeting company targets
- Conformity of the production drawings, standards and other requirements
- Cost- effective production
- Company's profitability
- Customer satisfaction [4]

Steel workshop consists of the following employees:

Table 5. Steel workshop employees structure [11]

Employee	Quantity
Production manager	1
Production manager's assistant	1
Foreman	1
Chief specialist	1
Specialist	1
Painter	2
Assembler	5
Sawyer	2
Welder	4
Miller	1
Cleaner	2
Grinder	3
Packer-loader	1
Total:	25

Steel workshop has the following machines:

Table 6. Steel workshop machines

Machine	Quantity
Single saw	1
Double saw	2
Glazing bead saw	1
Welding machine	4
Milling/drilling machine	3
Assembling and testing stand	1
Powder painting chamber	1
Total:	13

After receiving the order, designers make confirmation drawings. As soon as acceptance of solutions is received and signed down from customer side, designers prepare a summary of material and necessary fixtures required for certain project and send to production manager, who is responsible for ordering the components taking into consideration the time schedule. Due to the fact that the production is project based, the warehouse keeps only necessary material needed for projects that are currently or in near future in work. Some, the most common reserve components are also stored on workshop area. Normally, the new material, mainly profiles, arrive once a week and other small fixtures and components, like locks, striking plates, screws, gaskets, etc., arrive 2-3 times per week, if necessary, then more often and delivered by courier. That is why proper and correct material summary should be done to provide smooth production and on time delivery.

When profiles arrive, they are being stored in warehouse that is situated near the sawyer workplace. Profiles are loaded into sawing machines manually. The sawyer adjusts the necessary angles according to cutting list provided together with drawings and runs the cutting machine. Next stage after cutting is milling. With the help of milling machines, the necessary holes are prepared. The work is implemented manually, meaning that no CNC programming is used. Basically, main operation performed by milling machines is milling operations and drilling the holes. Processing is performed according to designer AutoCAD 2D drawings, where all necessary information is indicated. Without any analyzing, it seems that the main bottleneck is milling operations, because workers need to mark manually all the holes and it definitely takes much time. However, total there are three milling workstations that compensate fast sawed profiles delivery.

At every stage, visual control is carried out, meaning that if some defect is identified, it is being sent to previous workstation for repair. Next operation after milling is welding, where profiles according to drawing are welded together. In case, some defect is revealed, it is being sent to previous operation or corrected at the place. After frames are welded, they are moved to grinding, where all the welds are polished and prepared for the painting. A couple of month ago, Metus-Est AS started to use powder painting instead of wet painting. There are many reasons why. For example, powder painting:

- Powders offer excellent coating properties;
- Powders are more eco-friendly to the environment than solvents;
- High efficiency (use of 95% powder);
- Speed (coating solidifies fast enough, about 30 min.);
- Operator training for powder coating is easier;
- Reduced the risk to operators' health;
- Reduce risk of ignition;
- Strength. Such a coating has excellent physical and mechanical properties;
- Durability. Even in the most critical weather conditions during the useful life of the coating is 50 years, in case of strict compliance with powder coating technology;
- Decorative. Powder paint has a fairly wide range of colors - more than 5000 textures and colors.
- Powders - is the lack of problems associated with waste disposal.

Paint layer thickness control is performed once a day by assembler, who controls the thickness of painted surface one random steel element with thickness gauge tool. After measurement, all results are recorder in control sheet and signed down. The example of control sheet is provided in *Appendix 1*.

After paint control is carried out and in case of no deviations, the element is moved to next stage of preassembling. In case testing reveals inconsistencies with the standards, the element need to pass the stage of polishing and removing the paint layer and after that to pass one more time painting operation. Preassembling operation consists of assembling the door with required fittings, like locks, striking plates, door closers, door coordinators, handles, different sensors etc. After all the necessary fixtures are installed, then it is required to control how all components work together. Testing is carried out on special stand where all functions and their compatibility is checking to prevent any incompatibility and inoperability. The example of given document is provided in *Appendix 2*.

In case some defects are found, they are recorded in table and are eliminated. Basically, all the inconsistencies and deviations can be fixed by assembler. If there are serious problems, then they are repaired on other workstations. Also if no serious problems revealed, then after getting signature, elements can be transported to neighbor working place, where final assembling is implemented.

The final assembling stage consists of installing glazing of beads, gaskets, thresholds and other structural elements. After that, visual control is performed and production is ready for packaging. Packaging is performed according to packaging specification that assigns project manager and if no special requirements are brought, then packer completes pallets according to standard regulations taking into consideration maximum allowed weight and dimensions of steel elements per one pallet.

3.2. Manufacturing process modelling

Modelling is a powerful and effective tool for a variety of objectives, systems and processes in various areas of human activity. This is a very complex and multi-phase systems, the investigation process, that helps to describe existing process, to simplify it, validate , simulate and further to carry out exploration to solve various tasks. The modelling is very important in case new model of process need to be built up or modified.

There are many benefits that process modelling allows to achieve:

- Ability to choose correct action by testing every aspect of a proposed change without making additional investments;
- Compressing and expanding time allows to speed up or slow-down desired process or operation and see the difference within short period of time;
- Understanding why every change is important and what consequences it can bring;
- Explore possibilities in the operating procedures, methods and results even without disrupting the real system;
- Diagnose problems coming from changing the variables and making the necessary conclusions;
- To eliminate bottlenecks and non-value adding operations. [14]

To visualize and simplify perception of company processes, make them transparent and arrange them in a logical sequence. In order to simplify perception of manufacturing process there was used SmartDraw software. It is versatile and simple way to create different drawings like flowcharts or floor plans. The result is presented below (see *Figure 14*).

Legend:

1. Janisoft/Kbk file – sheet, that consists of cutting list and installation rules, created by Janisoft or Stalprofil Kbk software.
2. WPS – welding process specification
3. RAL/NCS catalogues – catalogues with painting regulations
4. Production catalogues – catalogues of fitting suppliers like Abloy, Assa, Dorma etc.

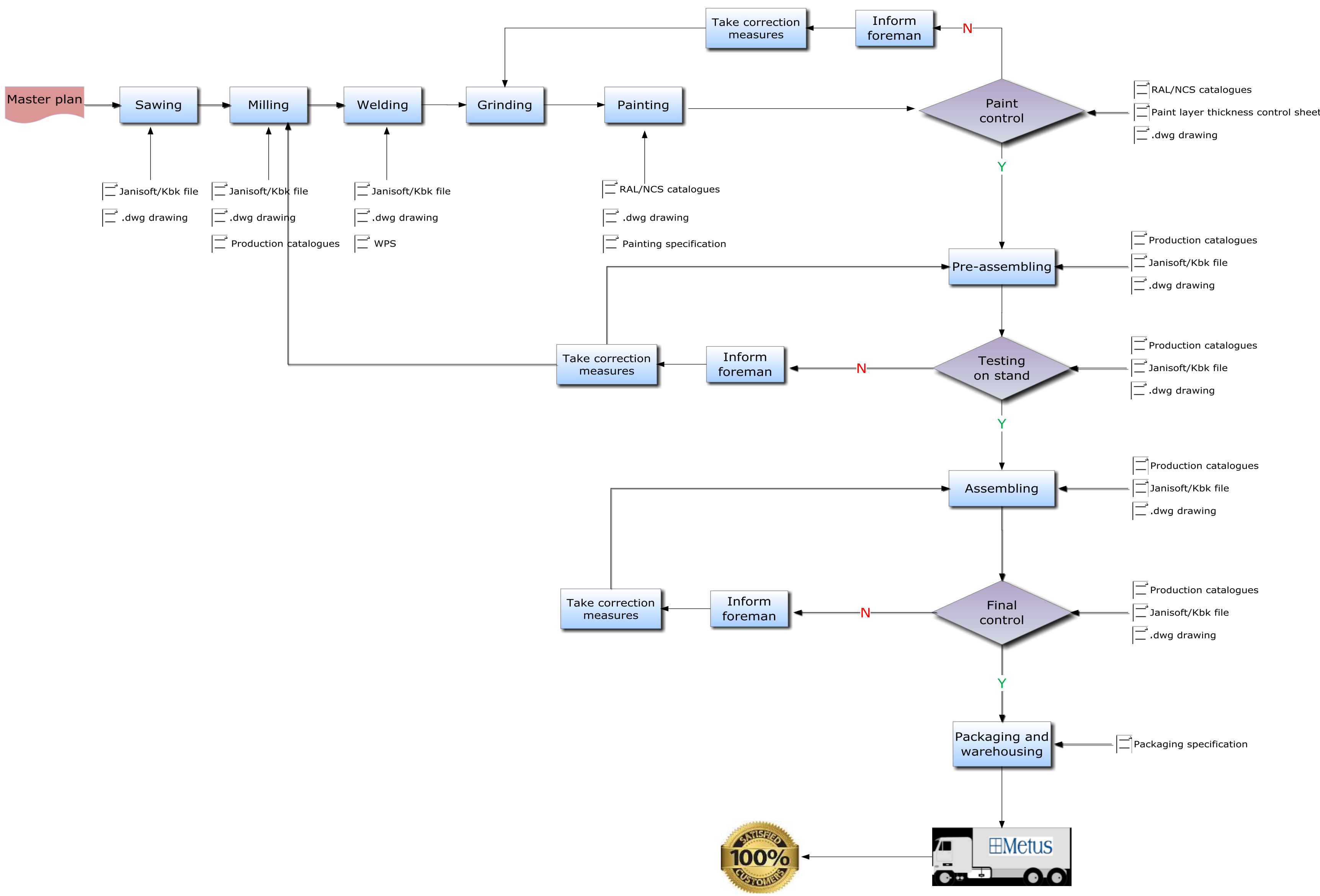


Figure 14. Manufacturing process flowchart

Particularly in given work in order to simulate processes was chosen developed by InControl Solutions Enterprise Dynamics Simulation Software. This software is based on a discrete-time event-driven simulation method. The event-driven simulation is based on the order of events. Event highlights its related objects and then the reaction creates these objects further events.

3.2.1. Enterprise dynamics

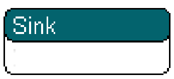
Enterprise Dynamics (ED) is simulation software platform that allows making design and implement simulation solutions. Due to this software, company has a great opportunity to analyze, visualize and optimize the performance of assets and investments, to solve any complex people, technology, process and infrastructure related challenges using resources in a more rational way. It allows to solve any problem virtually and by experimentation find solutions for a given problem or an answer for particular question. [15]

The main advantages of using Enterprise Dynamics are:

- Virtual optimization: allows virtually to create, analyze and improve any scenario of the entire system lifecycle without any disturbances of current system and moreover to decrease the implementation period;
- Improve communication: visualization allows improving communication level and enabling to lead negotiations in a more effective way;
- Manage complexity & variation: software offers tool to create insight of the system;
- Planning & preparation: allows to optimize resource planning system and answer any sort of questions related to processes;
- Return on investment: software enables to evaluate and manage future resource investments. [15]

Main objects that were used for manufacturing process flow visualization is presented via table below (see *Table 7*).

Table 7. Enterprise dynamics main objects [16], [17]

Icon	**Name**	**Function**
	Product	Allows the physical flow modelling. The flows can consist of goods, products, persons or documents
	Source	Allows products to enter the model at a specified rate and functions as a product or customer generator
	Server	Shows the machine setup time, operation time and cycle time.
	Queue	When the next source (machine) is busy, then the queue atom collects products in a queue.
	Multiservice	Allows to carry out preparation of the next product during the processing time of main product
	Conveyor	Shows the distances between sources and servers, allows to set transportation time
	Sink	Shows the number of products produced

In recent years, it has become very popular implementation of Lean techniques that has many benefits like:

- Reduction of manufacturing time;
- Reduction of lead-time;
- Elimination of non-value adding processes and operations;
- Usage of resources in a more rational way;
- Elimination of wastes;
- Achievement of better relations with stakeholders and customer satisfaction. [19]

In fact, not less effective method could be also simulation technology that can save costs even in case of small batch production, which should match exactly the Estonian market. Simulation technology allows the user to create a new virtual factory, using the existing standard components, and to form a wide variety of both equipment location plans. Thanks to a very accurate simulation, it is possible to show how the production line is going to work.

Moreover, simulation modelling allows improving and optimizing processes before real production line is built. Simulation allows within seconds to change parameters and analyse the results, change the design of location of factory workshop. Almost all existing and coming ideas referring to material or workforce planning, equipment placement and setting, production methods and environment, is real and easy optimize is case of need. [18]

Shorty, simulation can be characterized as a tool allowing:

- Visualizing current or future process within short period of time
- Eliminating bottlenecks and study the reasons for them
- Making perception of company work more clear and transparent
- Carrying out changes, tests and analyses without physical costs
- Making easier to decide and build company strategy [18]

3.2.2. Initial data collection

Key factor in modelling process and simulation plays accuracy of initial data. The more accurate and reliable data is, the more real picture will appear after simulation. To achieve reliable results it is recommended to spend more time on checking the initial data, controlling the numbers more than once in order to be sure in future results.

The accuracy of measurement operations depends on observations quantity. The more accurate results are needed the more observations need to be taken. Activity sampling is very popular way to measure the time of activities machine or people spend on. [28]

Particularly, in current thesis there was spent much time on measuring the current process preparation and operation time. As a measuring tool was used standard mechanical stopwatch. Taking into consideration the fact, that company manufacturing process is built on project type, meaning that there are no similar products from order to order. For this case there were measured general parameters that can be used for all other projects. For example:

- Sawing (measured time needed for preparation of profiles, setting desired angle of cutting and time needed to cut one angle depending on profile system);
- Milling (measured time needed for preparation of sawed profiles and main operation time needed for milling the specific fitting (drilling holes for magnet contact, lock, striking plate, door closer, etc.) depending of profile system);

- Welding (measured time needed for preparation of milled profiles, operation time needed to weld one corner depending on profile system);
- Grinding (measured time needed for preparation of welded frames, operation time needed to polish 1m of profile);
- Painting (measured time needed for preparation of polished frames, time for preliminary heating the frames before painting depending of desired environmental class, operation time needed to paint one batch of frames depending on profile system);
- Assembling (measured time needed for preparation of painted frames, assembling time for one fitting (mounting lock, striking plate, door closer, magnet contact, etc.), time for installing one glazing bead, 1m of gaskets, time for screwing one screw etc.);
- Packaging (measured time needed for preparation of assembled doors, packaging or operation time for one door).

Besides the preparation and operation time, it was necessary to consider deviations from normal time. Differences may occur from workforce competency, skills, time period, state of health, etc. In order to bring time measurements to ideal it was used law of normal (Gaussian) distribution. The meaning of a normal distribution becomes clear from its graphic shape (see *Figure 15*). The most probable value of the random variable is situated near its peak (average). As the distance from it, the probability value is reduced and if the value is located in the "tail" of distribution, then probability is very unlikely. [20]

Normal distribution is most widely used in simulation modelling. Often it is utilized for definition of random variables in general-purpose simulation systems, if they are not determined by other way. Normal distribution is subject to the amount of a sufficiently large number of independent random variables described by whatever distribution laws. The more random of random variables are being summed, the more accurate approximation is performed. Majority of the values encountered in practice are measurement errors, they can be represented as the sum of a larger number of small terms - elementary mistakes, each of which is caused by a separate independent cause [20]

The Normal distribution parameters:

Possible applications	Identification of different types of errors
Density	$f(x)=\frac{1}{\sqrt{2\pi\sigma^2}}$ - for all real *x* numbers
Distribution	No closed form
Range	$(-\infty, \infty)$
Mean	μ
Variance	σ^2

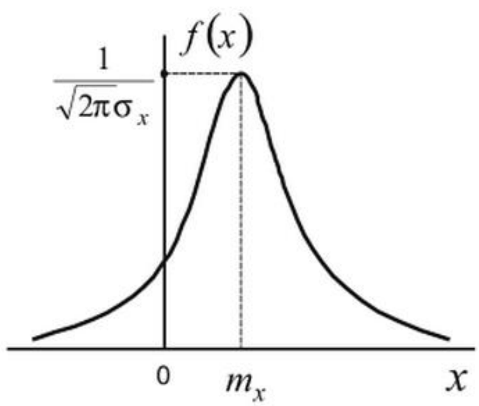


Figure 15. Graphic of normal distribution [20]

For manufacturing process simulation were taken into account 9h working day, one hour of which was rest time. Moreover preparation, operation, auxiliary and additional times were calculated. Also, transportation time from one working place to another was considered. Visualized distribution of working time for better perception is presented below (see *Figure 16*).

Basically, total working day time consists of pure working time and rest time. For resting time employee is entitled to get 30 minutes lunch time and 30 minutes for resting that is split by two working pauses. Pure working time components are calculated separately and used for simulation analysis.

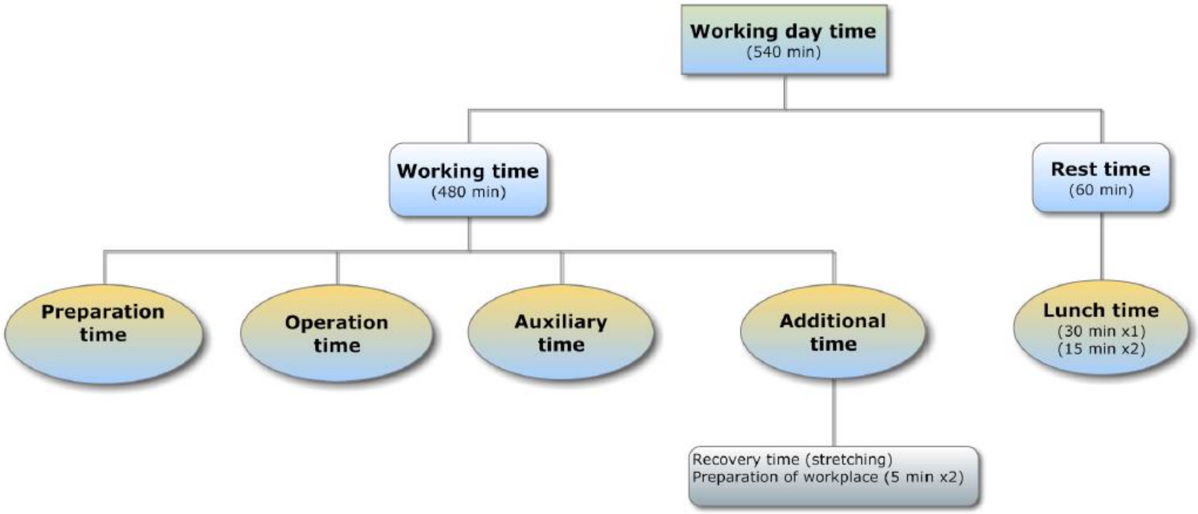


Figure 16. Distribution of working day time

3.2.3. AS-IS Manufacturing process simulation

After the initial data was collected and time for operations was assigned, it was necessary to build the real process in Enterprise Dynamics software. Using standard atoms, described in *Table 7*, manufacturing process has been modelled.

In fact, first sawing operation was not taken into account, because there are total four sawing machines that cope with the workload and do not work all the day. Normally, they cut profiles in advance, store cut profiles near the milling machines and average capacity of each sawing machine is 30-40%. Because of that in ED sawing machines were replaced by atom stock and established limitation of 15 products/day.

The results of simulation are presented below (see *Figure 17*).

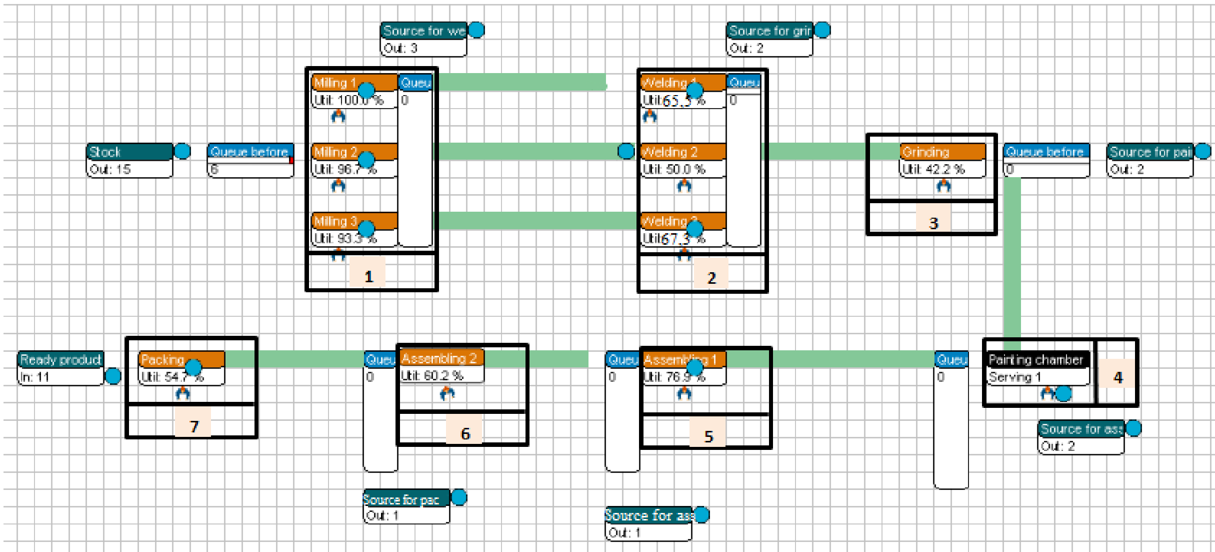


Figure 17. AS-IS manufacturing process simulation results

Workstations are split by groups and are located according to real positioning in factory. The following groups are:

- 1 – milling operations;
- 2 – welding operations;
- 3 – grinding operation;
- 4 – painting operation;
- 5 – preassembling operation;
- 6 – assembling operation;
- 7 – packing operation.

For better perception, the same process is built also in 3D dimensional image.

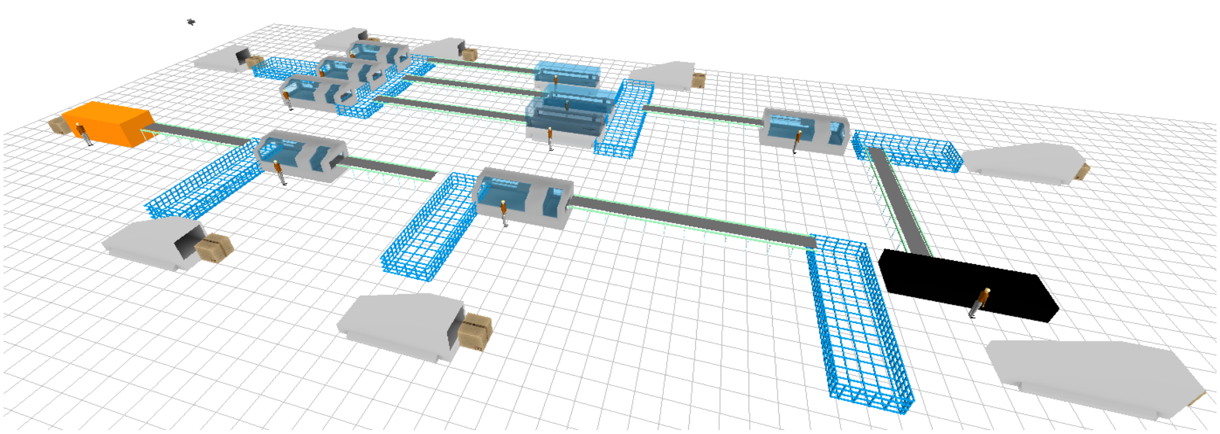


Figure 18. AS-IS manufacturing process simulation 3D model

Figure 17 and *Figure 18* present manufacturing process simulation results taking into account collected working times. The time spent on every process is shown below in *Table 8*. Table consists of total time for one operation, meaning that preparation, operation, additional and auxiliary times were summarized. The aim was to figure out workstation that was overloaded, not the single operation or motion that process consists of.

Table 8. Processing time of workstations

Workstation	**Processing time, min**
Milling 1	183 ± 10
Milling 2	183 ± 10
Milling 3	183 ± 10
Welding 1	120 ± 8
Welding 2	120 ± 8
Welding 3	120 ± 8
Grinding	25 ± 5
Painting	66 ± 10
Assembling 1	34 ± 8
Assembling 2	25 ± 8
Packing	25 ± 8

After simulation, it became clear that the main bottleneck is milling machines. Workers do not manage to support volume and flow of raw material, because all the manipulations like marking holes, fixation of profiles, tool replacement are carried out manually. Moreover, in case of new fixtures, very often workers spend additional time on searching and checking extraordinary catalog solutions.

Below is presented chart of workstations loading (see *Figure 19*).

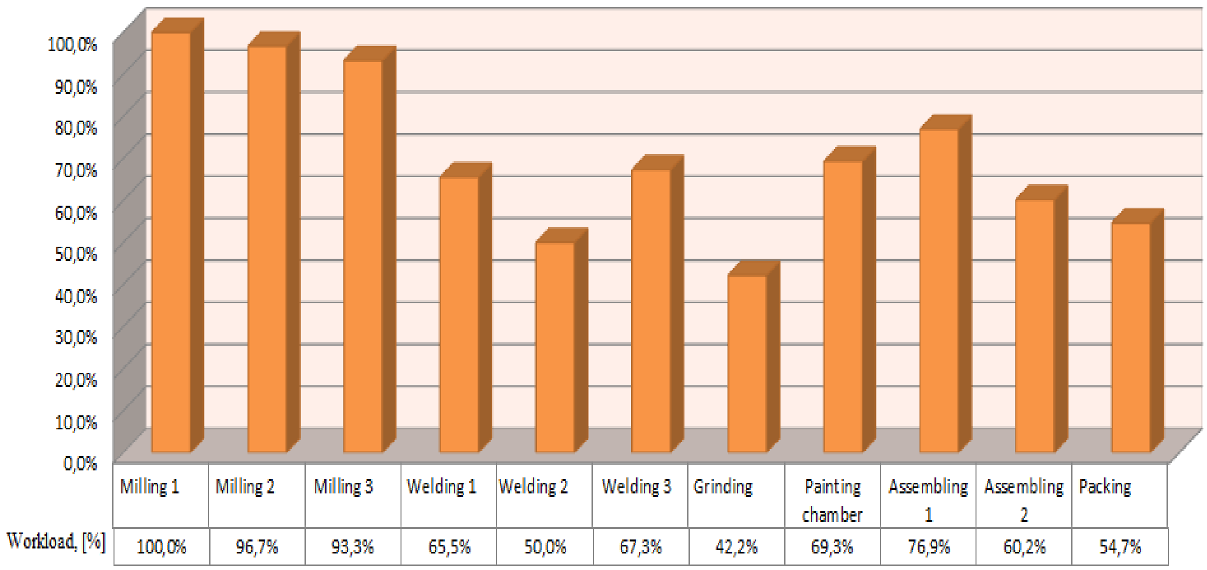


Figure 19. AS-IS loading of workstations

Below is presented chart of workstations loading in decreasing order (see *Figure 20*). It is clear that all milling machines are overloaded. Moreover, workload of grinding, packing, welding 1 and assembling 2 workplaces is too low and need to be increased. The aim of every production is to achieve equal distribution of workstation and workforce workload.

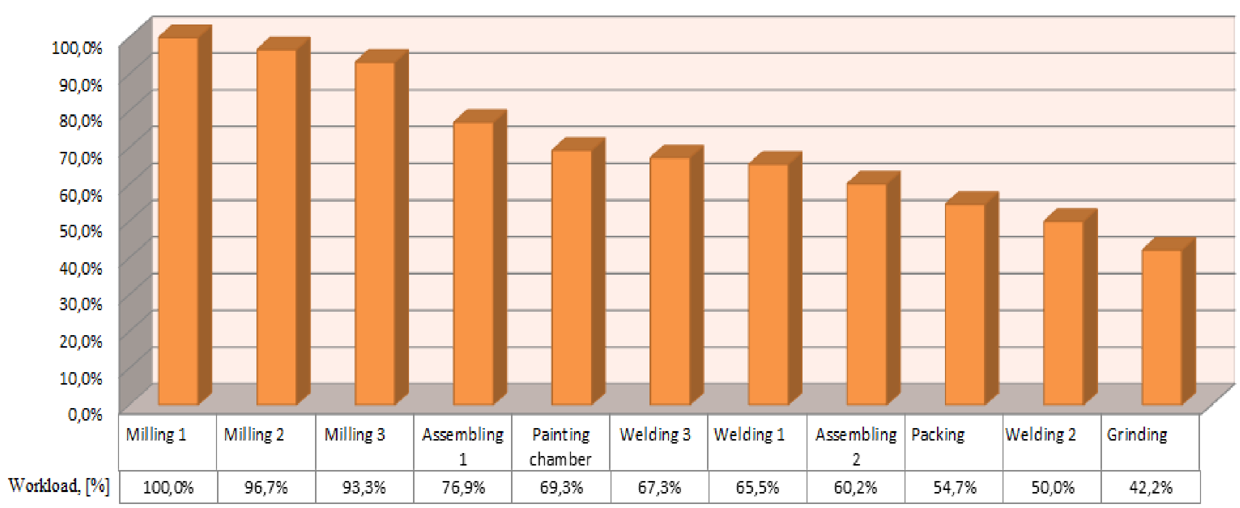
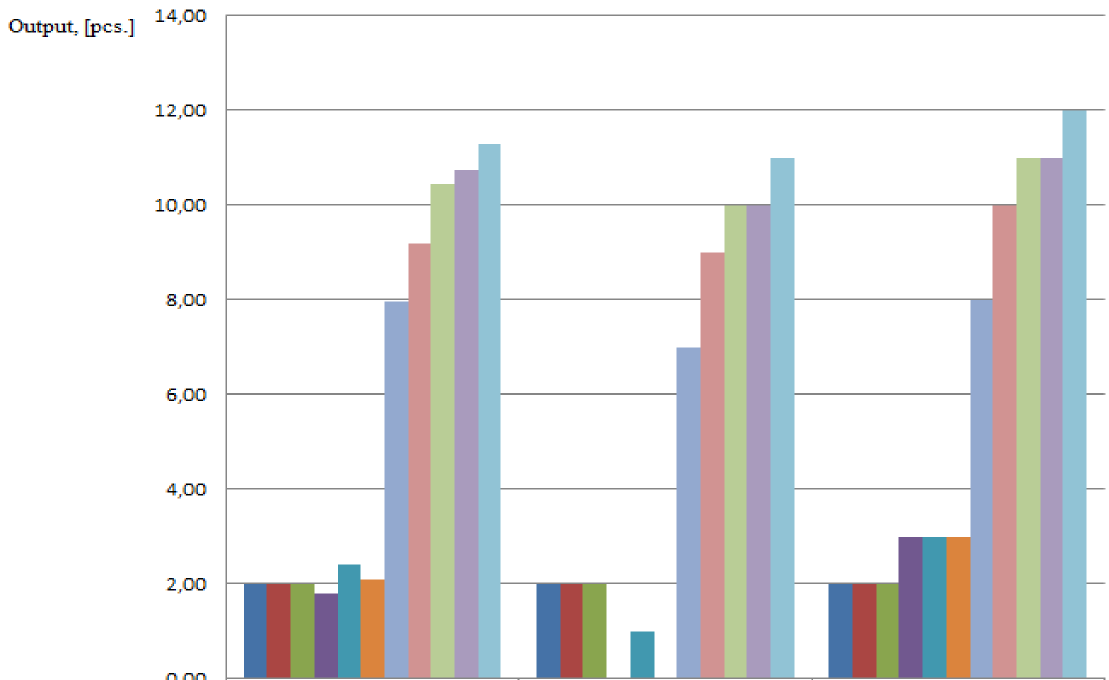


Figure 20. AS-IS loading of workstations in decreasing order



	Average output, [pcs.]	Minimum output, [pcs.]	Maximum output, [pcs.]
Milling 1	2,00	2,00	2,00
Milling 2	2,00	2,00	2,00
Milling 3	2,00	2,00	2,00
Welding 1	1,80	0,00	3,00
Welding 2	2,40	1,00	3,00
Welding 3	2,10	0,00	3,00
Grinding	7,95	7,00	8,00
Painting chamber	9,20	9,00	10,00
Assembling 1	10,45	10,00	11,00
Assembling 2	10,75	10,00	11,00
Packing	11,30	11,00	12,00

Figure 21. AS-IS output of machines per 8 hours

In order to investigate why does the milling process takes so much time , it its decided to split it by single operations. These operations with working times are presented in following flowchart below (see *Figure 22*).

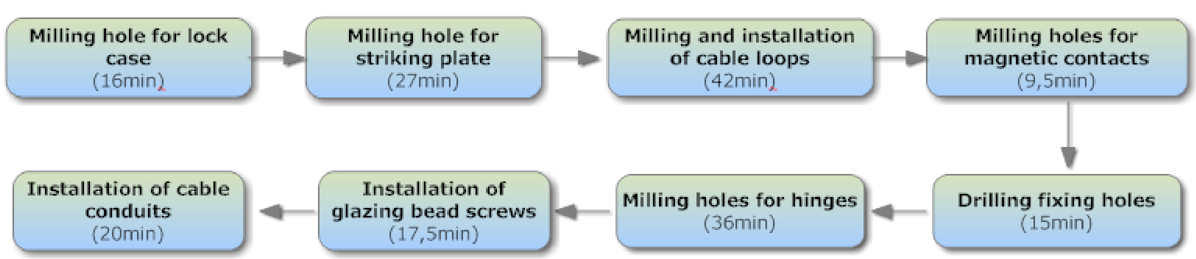


Figure 22. AS-IS sequence of milling operations

Operations take much time because they are implemented manually. It is clear that milling operations need to be accelerated in order to load downstream situated machines more and provide smooth production with equal distribution of workload.

3.3. Manufacturing process redevelopment

Every company wants to be the first on the market, constantly grow the profit and to have best reputation. Thus, in order to be the first it is necessary to change strategies depending on market conditions and forecasts. Basically, there are two main possibilities that company managers usually follow. First strategy is focusing on whole enterprise and global changes in all divisions. The second possibility is to carry out local changes, usually on shop floor level and trying to eliminate different types of waste that do not bring value. [21]

Very often it is not sufficient to have only one of two or both strategies implemented. Moreover, it is important to develop and control processes continuously in order they would be all the time actual and ideal for current production type or volume. Many popular tools and philosophies end with final stage of control or development. For example, Six Sigma has methodology DMAIC (define-measure-analyse-improve-control) based on PDCA (plan-do-act-check) Deming circle and ending with control stage. Moreover, one of the final tools of Lean Manufacturing is Kaizen (philosophy of continuous improvement strategy). [22]

3.3.1. Manufacturing process improvement

According to manufacturing process simulation results, it became clear that the main bottleneck is on milling operation stage. Time spent on milling and capacity of machines is very high and it is the first workplace need to be improved to allow smooth production. The main point of each type of production is that the machines will be loaded equally.

The main factors that decrease the efficiency of current milling machines are:

- Manual fixing of profiles;
- Manual marking of holes;
- Additional time needed if case of dealing with new products/fittings;
- Low speed of manual cutting/milling;

- Errors coming from human factor;
- Reduction of efficiency by the end of working day.

The aim of the process improvement is to eliminate described above factors in an efficient way. One way to achieve it is to change manual milling machine by CNC. At current stage it is not completely clear how many machines need to be changed. It will become clear after carrying out additional simulation. There are many advantages of using CNC machines that can support the manufacturing volume:

- High performance;
- Reduced processing time;
- High accuracy and quality;
- Quite simple to learn: no advanced training needed;
- Less workforce needed per one CNC machine;
- Ability to work 24h;
- Raw material waste is minimized;
- Possibility to use CAM systems and exact design according to customer desires.

3.3.2. CNC machines comparison and selection

Searching for the necessary machine was carried out according to following factors. First of all, CNC milling machines should have had proper dimensions of working table to allow machining long profiles up to six meters. Also the overall dimensions of machines should have been suitable: not oversized in order to fit on production area and take minimum place for using production space more rational. Moreover, machines should have been able to machine not only structural steel, but also stainless steel. Stainless steel has higher strength, low thermal conductivity and self-strengthening properties during deformation. Also stainless steel is highly viscous material and it makes machining of it more complex if to compare with structural steel. In recent years, Metus-Est AS started to receive project of stainless steel products more and more often that is why new machine should have covered all the possible material variations that can appear. It was crucial that machine would have had acceptable price and good quality level. In addition to that, one more important point was that machine would be easy to manage and easy to be taught for operating with. Simplicity in operation will help to avoid problems and minimize additional investments for training the workers and minimize the period when the machine will start working on maximum efficiency.

The machines that were preselected are presented below.

Figure 23. SLP-8000 milling center [23]

Figure 24. SBZ 130 eluCAM machining center [24]

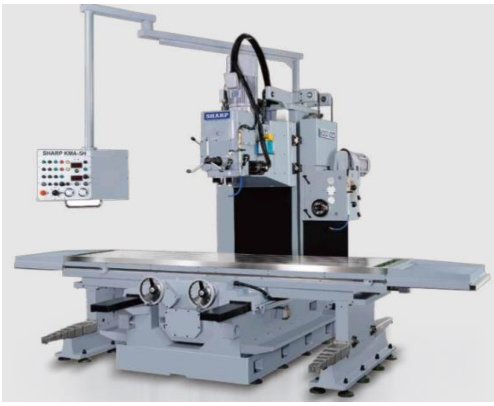


Figure 25. Sharp KMA-5H milling machine [25]

Figure 26. GBR 3 milling machine [26]

In order to choose suitable milling machine it was necessary to lead a research and compare different machines using table and matrix way of comparison. As a key tool for leading the research was used *Factor-Rating Method*, but little modified and adjusted to current case. The core of given method is to simplify selection and comparison of different subjects taking into account decision criteria and applying weights to those criteria. In current case it was used 10-point scale for decision making (see *Table 9*). [27]

The more points machine, get the better it is. For example, score 10 in price means that machine has the best price in comparison with current competitors.

Table 9. Factor rating method comparison table

	Machine/Factor	Appropriate dimensions of working table	Ability to machine structural/stainless steel	Ease of operation	Durability/ quality	Price	
Factor score	**SLP-8000**	10	10	10	9	8	
	SBZ 130 eluCAM	10	10	9	10	8	
	Sharp KMA-5H	6	10	8	8	10	
	GBR 3	7	10	8	8	8	
Factor weight	**Total: 100**	20	28	10	27	15	**Total score**
Weighted score	**SLP-8000**	200	280	100	243	120	943
	SBZ 130 eluCAM	200	280	90	270	120	**960**
	Sharp KMA-5H	120	280	80	216	150	846
	GBR 3	140	280	80	216	120	836

According to factor rating method analysis, it was became clear that winner scored total 960 points and winning machine is SBZ 130 eluCAM , product from German company Elumatec. Company was established in 1928. Currently, Elumatec is a leading premium supplier in segment of profile machining for a vast array of different requirements and materials. The range of products was wide enough and the choice has stopped on profile machining centres. Standard milling machines were not suitable because of limited width of working table and overall dimensions. Optimal machining centre required for Metus-Est AS production is SBZ 130 eluCAM, 3-axis profile machining centre (see *Figure 24, Figure 27*).

The machine is suitable for different types of material: aluminium, steel and stainless steel. It covers all the material types used in Metus-Est AS. Machine allows making routing, drilling and tapping operations. On-board turret head, equipped with 8 tools or angle heads, ensures that tool changing times are kept very short, thereby optimising working cycle. Moreover, machine has automated clamps that allow fast positioning of profiles.

<u>SBZ 130 eluCAM technical specification:</u>

- Traverse path X-axis, 4,200 mm, 7,200 mm, 8,500 mm, 10,200 mm, 11,500 mm (additional lengths on request) Vmax. 60 m/min.
- Traverse path Y-axis, 485 mm, Vmax. 30 m/min.
- Traverse path Z-axis, 340 mm, Vmax. 30 m/min.
- Spindle speed 6,000 rpm max., 18,000 rpm with high-speed spindle
- Spindle power output 5.5 kW
- Tool changer for 8 tools on a turret head

- Compressed air supply 7 bar
- Power supply 400 V, 3~, 50 Hz, 35 A
- Air consumption per minute approx. 100 l with spraying

Moreover, machining centre can be equipped with different length of table. It is very important, because it allows choosing required table length according to production and product types. Possible lengths are presented below:

SBZ 130 eluCAM machining length

SBZ 130 – 4.2 m

- Max. processing length with profile end machining, 4,080 mm
- Max. processing length without profile end machining, 4,200 mm

SBZ 130 – 7.2 m

- Max. processing length with profile end machining, 7,080 mm
- Max. processing length without profile end machining, 7,200 mm

SBZ 130 – 8.5 m

- Max. processing length with profile end machining, 8,380 mm
- Max. processing length without profile end machining, 8,500 mm

SBZ 130 – 10.2 m

- Max. processing length with profile end machining, 10,080 mm
- Max. processing length without profile end machining, 10,200 mm

SBZ 130 – 11.5 m

- Max. processing length with profile end machining, 11,380 mm
- Max. processing length without profile end machining, 11,500 mm

SBZ 130 eluCAM options

- Shuttle operation for working on two sides
- Automatic length measurement
- Chips conveyor belt
- Angle router heads

- High-speed spindle
- Slow spindle
- Clamping unit accommodates double profile machining
- Barcode scanner
- Collet chucks
- Collets
- Tools
- EluCad (office software package for optimised production management)

Figure 27. SBZ 130 eluCAM profile machining center, real picture

3.3.3. TO-BE Manufacturing process simulation

After selection suitable machining centre it is required to analyse how does the implementation of new machine affect manufacturing process. Repeated simulation procedure was carried out according the same plan as initial AS-IS simulation.

Initial data for TO-BE simulation was the same except of milling operations. Before there were three manual milling machines doing absolutely equal work. After the application of CNC machining centre it was decided to move all the operations, that can be done without help of workforce, to CNC machine and some operations, that definitely need participation of workers, leave on manual working place. New sequence and time of milling operations is presented below (see *Figure* 28)

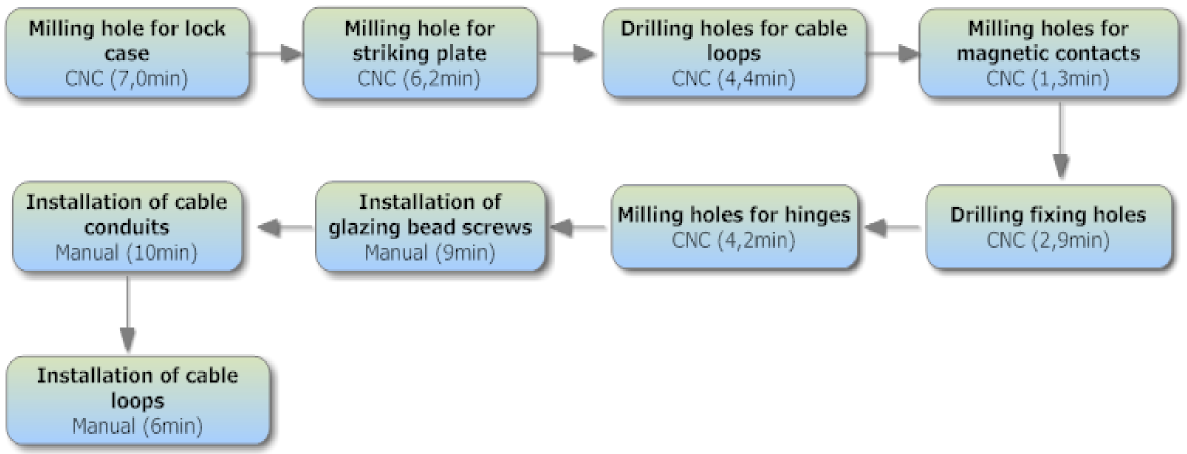


Figure 28. TO-BE sequence of milling operations

According to new a sequence, first six operations are carryed out on CNC machine and three others are made manually. Decisions according to new manufacturing sequence are presented below:

1. Refuse from two manual milling machines

After purchasing new CNC machine, the need in existing manual milling machines will be lost. One of three milling machines will remain on its place in case of additional help for CNC machine is need and testing of machine is finished.

2. Refuse from one milling working place

The need in one working place will be lost and the worker will be moved to assist miller in manual operations. It would be easier and faster when two workers handled together one massive and bulky door.

3. Change milling operation sequence

According to new sequence, first operations will be carried out on CNC machine and rest operations like installation of glazing bead screws, installation of cable conduits and installation of cable loops will be done manually.

New manufacturing process simulation results are available below (see *Figure 28*).

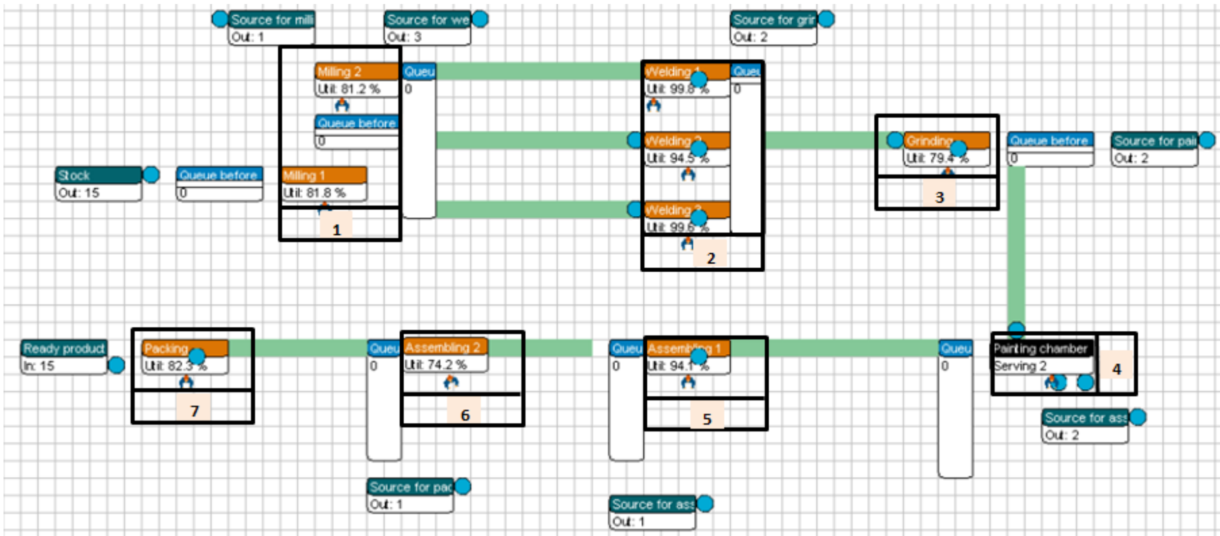


Figure 29. TO-BE manufacturing process simulation results

After simulation with new CNC machine and modified sequence of milling process, it became clear that one CNC machine is capable to replace existing manual machines and cope with current loading. All downstream processes received higher workload and machines got more equal distribution. It is better, because now process is more smooth and well-balanced; people have more equal distribution and throughput of goods is higher.

The results of new capacity of machines are shown below (see *Figure 30*).

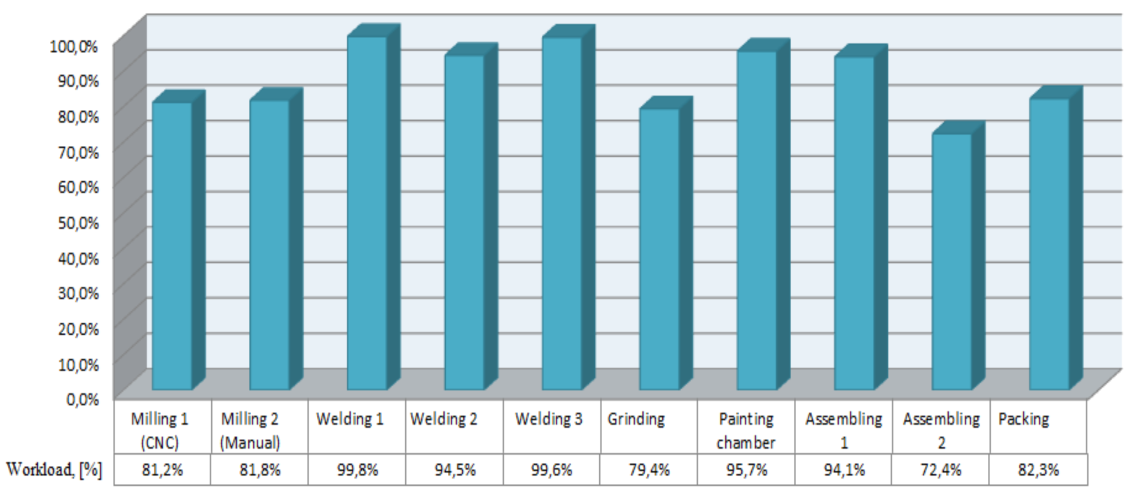
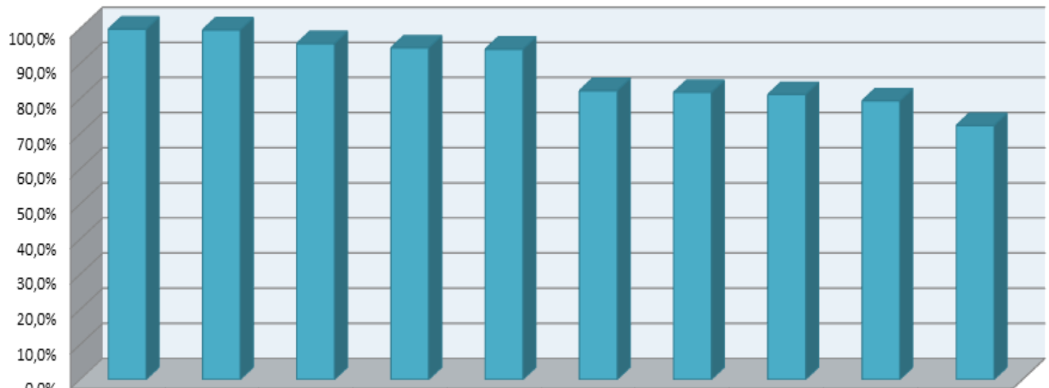


Figure 30. TO-BE loading of workstations

Below is presented chart of workstations loading in decreasing order (see *Figure 31*).

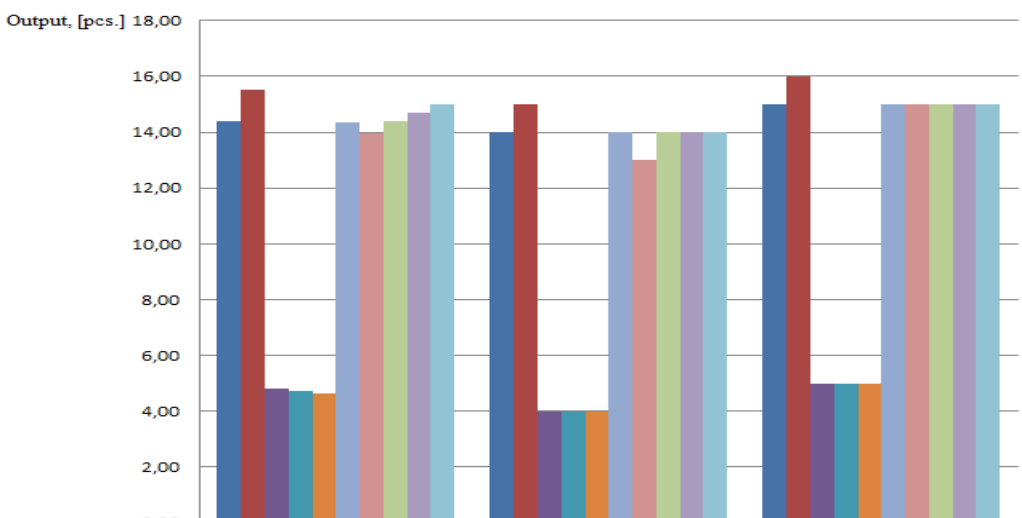


	Welding 1	Welding 3	Painting chamber	Welding 2	Assembling 1	Packing	Milling 2 (Manual)	Milling 1 (CNC)	Grinding	Assembling 2
Workload, [%]	99,8%	99,6%	95,7%	94,5%	94,1%	82,3%	81,8%	81,2%	79,4%	72,4%

Figure 31. TO-BE loading of workstations in decreasing order

After redevelopment, machines workload distributed according to *Figure 31*. The most loaded workstations became welding 1 and welding 3 that have capacity more than 99%. The less loaded workplace is assembling 2 and has 72, 4% capacity.

New output of machines is shown on figure below (see *Figure 32*)



	Average output, [pcs.]	Minimum output, [pcs.]	Maximum output, [pcs.]
Milling 1 (CNC)	14,40	14,00	15,00
Milling 2 (Manual)	15,50	15,00	16,00
Welding 1	4,80	4,00	5,00
Welding 2	4,75	4,00	5,00
Welding 3	4,65	4,00	5,00
Grinding	14,35	14,00	15,00
Painting chamber	13,95	13,00	15,00
Assembling 1	14,40	14,00	15,00
Assembling 2	14,70	14,00	15,00
Packing	15,00	14,00	15,00

Figure 32. TO-BE output of machines per 8 hours

Table 10 and *Figure 33* show the difference between the initial workload of machines (AS-IS capacity) and final workload after process redevelopment (TO-BE capacity).

Table 10. AS-IS/ TO-BE capacity and product output difference

Workstation	AS-IS capacity, [%]	TO-BE capacity, [%]	Workload difference, [%]
Welding 1	65,5	99,8	+34,3
Welding 3	67,3	99,6	+32,3
Painting chamber	69,3	95,7	+26,4
Welding 2	50,0	94,5	+44,5
Assembling 1	76,9	94,1	+17,2
Packing	54,7	82,3	+27,6
Milling 2 (Manual)	96,7	81,8	-14,9
Milling 1 (CNC)	100,0	81,2	-18,8
Grinding	42,2	79,4	+37,2
Assembling 2	60,2	72,4	+12,2
Product output, [pcs.]	11	15	+4

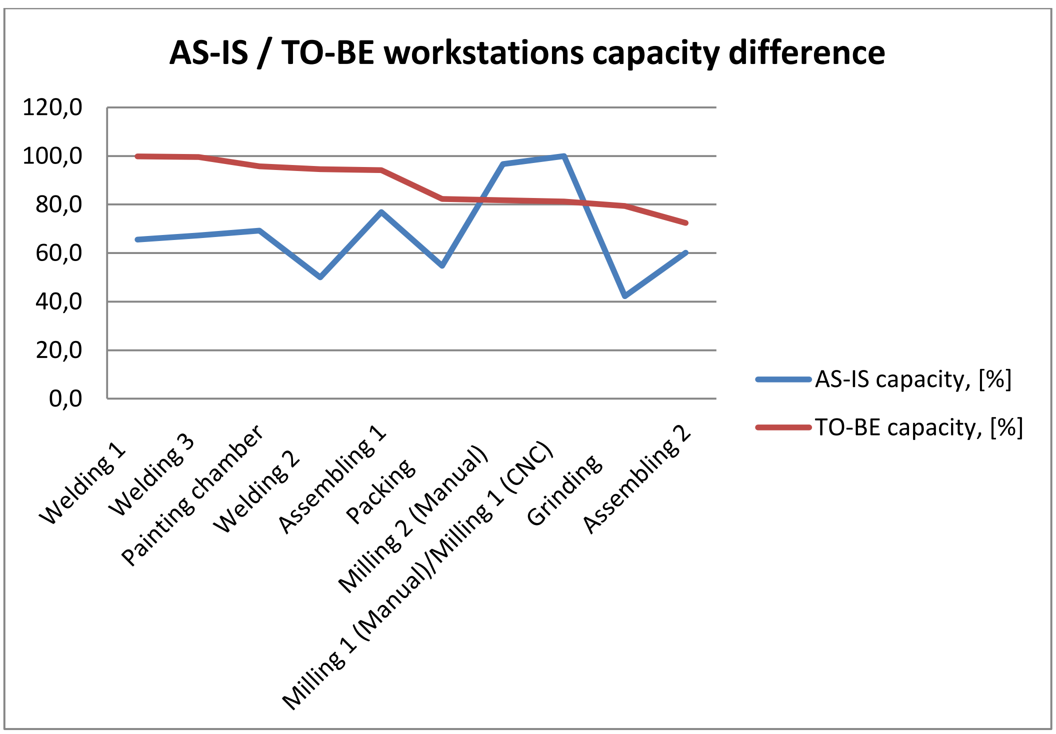


Figure 33. AS-IS / TO-BE workstations capacity difference

Starting analysing the results in *Table 10*, it is clear that indicators of machines capacity have increased significantly. Now workload of machine lies in range 72-99%, which is better than before, 42-100%. In additional to that, for better visual perception the difference in workstations capacities before and after process redevelopment is presented via chart (*see Figure 33*).

Moreover, output of final products has risen from 11 to 15 pcs. per one 8-hour shift. Meaning that improvements, described above, bring every week to the company 20 products more than before. In percentage relation production capacity has raised by 26%.

After process redevelopment the distribution of workstation capacities became distributed more equal through the production line. However, capacity of two welding machines (welding 1 and welding 3) has increased up to 99,6% and 99,8% respectively. For the moment, it is not sense in making additional improvement regarding the welding part, because as it is seen from TO-BE simulation analyses, there are no queues accumulating before welding operations. The reason is that because it is not completely clear how the door manufacturing process after simulation will work. It would be necessary to take additional measurements after production is ready to start working on new wave. It is most probable that processing time for welding operations will decrease relatively to times used in simulation.

Currently, welders are forced to fix sometimes errors coming from upstream production, from millers. Most common errors coming from milling operations are wrongly milled holes (at wrong place or wrong quantities). The errors are derivatives of human factor. Welders have to fix them and spend additional time from their working time. After purchasing new CNC machine, the quality of work will be definitely improved and decrease the time of correction the mistakes.

The other opportunity to decrease the loading of two milling machines is to use additional spare welding device that exists on factory. In addition, it is possible to save time thanks to better workspace organization, like using 5S/7S systems and implementing some lean methods to whole factory or partially in zones that most require it.

To sum, up local changes and improvements in capacities is possible to implement after the real situation becomes clear and after the new measurements were taken.

The necessary calculations regarding the return of investments (ROI) and profitability of the project are presented in next chapter.

4. ECONOMICAL CALCULATIONS

Economical calculations is very important part of the work with the aim of assisting information collecting that will help the company to make decisions related to financing. In the framework of thesis it is essential to calculate the profitability of investment to the project and find out the costs related to manufacturing process redevelopment. All the calculations are made by author of current thesis.

4.1. Product pricing

Generally, in price offer is also taken into account a reasonable profit margin, normally it is 5%-10%. For more complex products, margin is approximately 10% - 12%, in order to compensate possible unpredictable costs. The average project costs can be divided in following way:

- Material costs – 50%;
- Installation costs – 15%;
- Wages – 20%;
- Transportation costs – 5%;
- Overhead costs – 4%
- Profit – 6%

Taking into consideration the cost distribution policy, the price components for one SP 35000 fire resistant internal door will be calculated further (see *Figure 34*).

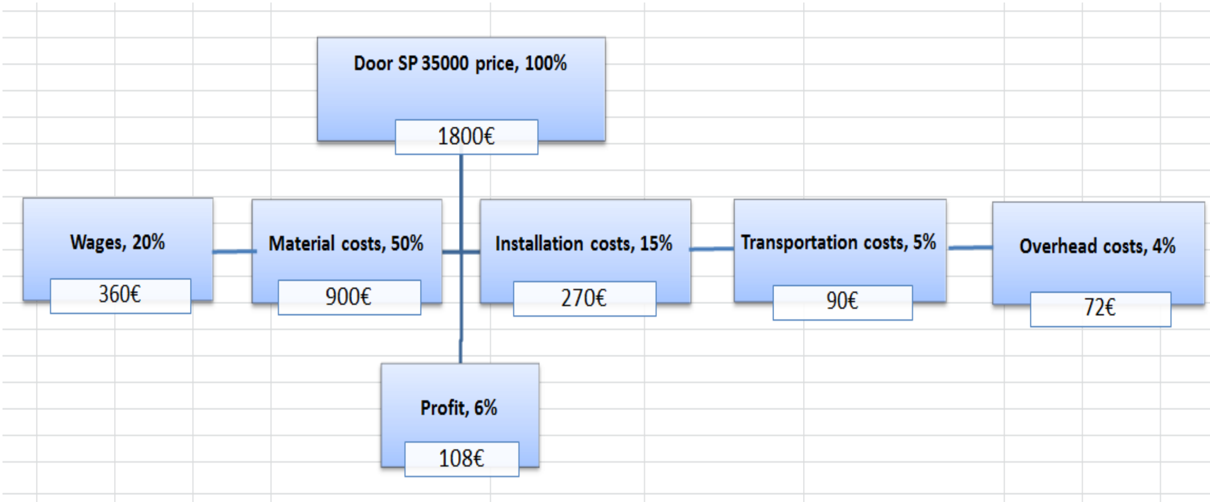


Figure 34. Cost distribution of SP 35000 door

According to cost distribution presented in *Figure 34*, it is seen that the pure profit per one door is 108€. The next chapter will consist of necessary calculations related to CNC machine purchasing and ROI calculations.

4.2. SBZ 130 eluCAM payback time

Related costs with CNC machine procurement are presented below (see *Table 11*).

Table 11. SBZ130 eluCAM procurement costs

№	Action	Quantity, [pcs.]	Costs, [€]
1	Purchasing of SBZ 130 eluCAM	1	150 000
2	SBZ 130 eluCAM installation and setting up	1	2000
3	SBZ 130 eluCAM maintenance costs, €/year		500
4	Dismantling of manual milling machines	2	200
5	CAM engineers and additional personal staff training	7	3500
6	Unexpected costs, €/year		500
		Total	**156 700**

Table 11 has two types of costs: one-time costs and annual costs. Annual costs consist of CNC machine maintenance costs and unexpected costs for any case.

Taking into consideration the fact, that every final product gives to company pure profit of 108€ and after the manufacturing process redevelopment, factory capacity has risen and is capable to produce four doors/day more. It means that every day company will get additional 432€ profit. This number will be used in further calculations.

Payback time calculation for CNC machine is presented below.

Payback period = $(p-n)/p+n_y = 1+n_y - |n|/p$ (4.2.1.)

Where

n_y – number of years after the first investment has been made at which the last negative value of cumulative cash flow occurs;

n – value of cumulative cash flow at which the last negative value of cumulative cash flow occurs;

p – value of cash flow at which the first positive value of cumulative cash flow occurs. [29]

Table 12. Cash flow during the year

Year	Cash flow, [€]	Cummulative cash flow, [€]
0	-156 700	-156 700
1	107 000	**-49 700**
2	107 000	**57 300**

Year 0 is the start point after purchasing the CNC machine and making the investments presented in table 11. The total costs for all investments is 156 700€. This value contains both types of costs, one-time and annual costs. Till the end of the year 1, it is necessary to calculate profit and subtract annual costs. The calculations are below.

Profit/year = profit/day * number of working days/year (4.2.2.)

Where

Profit/day – additional profit that company will start to ear after process redevelopment;

Profit/day = price for additional doors produced*number of additional doors produced

Profit/day = 108*4=432 [€]

Number of working days/year – number of working days in one year, in average it equals 250;

Number of working days/year = 250 [days]

Profit/year = 432*250 = 108 000 [€]

Annual costs are taken from table 11 and equals 1000 €/year.

Cash flow at the end of the year 1 is:
Profit/year - annual costs = 108 000 - 1000 = 107 000 [€]
Cumulative cash flow at the end of the year 1 is:
Cumulative cash flow at the end of year 0 – cash flow year 1 = -156 700 + 107 000 =
= -49 700 [€]

Cumulative cash flow at the end of the year 2 is:
Cumulative cash flow at the end of year 1 – cash flow year 2 = -49 700 + 107 000 = 57 300 [€]

Positive value of cumulative cash flow means that investment payback time has finished and company started to earn profit. Exact payback time calculation is carrying out according to equation 4.2.1.

Payback period = $(p-n)/p+n_y = 1+n_y-|n|/p = 1 + 1 - |-49\ 700|/107\ 000 = 1{,}53$ [years]

$n_y = 1$, because it is the last year, when last negative value -49 700 € of cumulative cash flow occurs;
n = -49 700 €, it is the last negative value of cumulative cash flow occurs;
p = 107 000 €, it is first value of cash flow when the first positive value of cumulative cash flow occurs.

As a result of calculations we receive that project payback period is 1,53 [years].

SUMMARY

Current thesis was associated with the production of steel doors in Metus-Est AS company. The main task of the thesis was to solve and eliminate problems defined in production process. These goals were connected with achieving smooth production without delays, increasing the productivity and shortening production time using contemporary methods for production analyzing, improving and eliminating existing bottlenecks.

The tasks required for achieving these goals are following:

1. *Company and production overview*

According to company overview, described in *Chapter 2*, Metus-Est AS is steel and aluminum glazed solutions manufacturing, and installation company. It has strong position on the market, keeping all key indicators positive. Company expands its market share, especially in Sweden (61%), less in Finland (22%) and Estonia (16%). Metus-Est has many strong partners both in Scandinavia and Estonia. Very important fact, that company is constantly having close relations to its partners, sharing experience and developing.

The main difference of Metus-Est AS from its competitors is coming from ambition to develop service structure, offering more sophisticated and complex solutions. Company is not dealing with similar mass products; almost every element produced in company is unique and designed according to customer demands.

2. *Manufacturing process overview and typical product selection*

Manufacturing process type is project based and service process type is professional. Manufacturing process is built on make-to-order concept. In order to bring out the most typical product, the statistics of sold steel elements for the year 2014 was carried out and according to sales chart presented in *Figure 4*, the most popular steel door appeared internal fire-resistant door, made of SP 35000 profile system.

3. *Manufacturing process modelling, time measurement.*

After the most typical product was selected, the next step was to describe existing manufacturing process. Using *Smart Draw* software the manufacturing process flowchart was created in order to define sub processes and bring out the sequence of operations for steel door

production. When the flowchart was ready it was necessary to define production times required for each operation. The measurement was carried out with standard mechanical stopwatch. Taking into consideration that production types is project based it was important to measure time that could be applied to other door types also. For example, there were measured times required for single operations depending on profile system or fittings used. Using this data, it is simple to evaluate production time for every door type, only what is need needed, to split every door by its single components and use measured data to calculate time for every part processing and further to sum up acquired results.

4. Existing manufacturing process modelling, simulation and analysis

After required initial data was collected, it was necessary to create model of existing process (*AS-IS*). For that case *Enterprise Dynamics* software was selected. The software allows making design and implements any complex simulation solutions connected to workforce, machines or process in a efficient way and spending minimum time. The results after the first simulation are available in *Figure 17*. In order to visualize the machines workload and capacity, different charts were created. *Figure 19* and *Figure 20* show the distribution of machine workload on production line. *Figure 21* shows the product output for every machine.

As a result, we received the bottleneck and queues before manual milling operations, which should be eliminated or modified to improve the manufacturing process.

5. Steel doors manufacturing process improvement

For the bottleneck elimination, it was decided to try replacing existing manual machines with automated CNC machine and analyzing the results.

First of all, selection of required CNC machine was carried out. Initially, four CNC machines, that are capable to machine structural and stainless steel, were preselected. In order to determine which machine would be suitable, the comparison of these machines were done using *Factor-Rating Method.* The core of given method is to simplify selection and comparison of different subjects taking into account decision criteria and applying weights to those criteria. In current case, those criteria were: appropriate dimensions of working table, ability to machine structural/stainless steel, ease of operation, durability/quality and price (see

Table 9). The 10-point scale was used for decision making. After filling the table and parameters multiplying, the winner appeared to be *SBZ 130 eluCAM* profile machining centre, which scored total 960 points.

6. *Future manufacturing process modelling, simulation and analysis*

After CNC machine has been selected, another simulation, taking into account capabilities of the machine, was implemented. As a result we received that one CNC machine is capable to replace two manual milling machines and eliminate the queues that were before. The results of *TO-BE* simulation are presented in *Figure 29*. Additional charts with machines workload are available in *Figure 30* and *Figure 31*. Moreover, in order to improve quality of milling operations was offered to change sequence of milling operations. According to new plan, all operations that could be done automatically will be machined on CNC machine and other operations that require human interposition and control will be done manually. New sequence of milling operations is presented in *Figure 28.* Also in order downstream workplace after CNC machine will manage to work at the same pace as CNC operator, the additional worker from former manual milling workplace will be taken for assistance. No one worker after process redevelopment should not be fired or hired, that will definitely support motivation of workers.

The results after process redevelopment are shown in *Table 10* and in chart form in *Figure 33.* According the results, output of final products has risen from 11 to 15 pcs. per one 8-hour shift. Meaning that every week company is capable to produce 20 products more. In percentage relation production capacity has raised by 26%.

Thanks to CNC machine and milling process reorganization, production process will become smoother, without queues and final products will have better quality.

7. *Economical calculations implementation*

In order to figure out the profitability of the project, it was important to lead economical calculations that will help the company top managers to make decision related to financial part. In the framework of thesis it was important to calculate the profitability of investment of the project and find out the costs related to manufacturing process redevelopment. First of all, the data was collected and costs related to procurement of CNC machine were calculated. The next step was to calculate payback time of CNC machine. Detailed calculation is presented in *Chapter 4.2.* As a result was received that CNC machine will pay back in 1,53 years.

All things considered, in the framework of current thesis, were used contemporary and modern methods for improving steel doors manufacturing process. Due to simulation software, the production line bottlenecks were detected and eliminated providing smooth production with equally loaded machines and workforce. Moreover, has managed to raise steel doors productivity by 26%. Using modern software and experience obtained in current thesis, there is an opportunity to assist future manufacturing process development, making necessary adjustments and simulations during the project faster and at minimum costs.

In further work, there is sense to carry out similar simulation for other product types and build up universal and optimized production line that will be suitable for every product type appearing in Metus-Est AS company.

KOKKUVÕTE

Käesolev magistritöö oli seotud terasuste tootmisega ettevõttes Metus-Est AS. Põhieesmärkideks olid tootmisprotsessi probleemide tuvastamine ning nendele lahenduse leidmine. Antud eesmärgid olid seotud sujuva ning viivitusteta tootmisprotsessi saavutamisega ning tootmisaja lühendamisega, kasutades kaasaegseid meetmeid tootmise analüüsimiseks, parendamiseks ning olemasolevate “pudelikaelade“ kõrvaldamiseks.

Vajalikud ülesanded nende eesmärkide saavutamiseks on järgmised:

1. *Ettevõte ning toodangu ülevaade*

Vastavalt ettevõtte tegevuse ülevaatele, kirjeldatud *Peatükis 2*, Metus-Est AS on alumiinium - ja terasprofiilidest klaasitud avatäiteid valmistav ning paigaldav ettevõte. Ettevõttel on tugev positsioon turul, kõik olulised näitajad on positiivsed. Ettevõte laiendab oma turuosa, eriti Rootsis (61%), vähem Soomes (22%) ning Eestis (16%). Metus-Est AS ettevõttel on palju tugevaid partnereid nii Skandinaavias kui ka Eestis. Väga oluline on fakt, et ettevõte on pidevalt ja tihedalt seotud oma koostööpartneritega, jagades kogemusi ning arenedes koos.

Peamine erinevus Metus-Est AS ja tema konkurentide vahel on soov arendada oma teenuste struktuuri, pakkudes keerulisemaid lahendusi. Ettevõte ei tegele masstootmisega: peaaegu iga firmas toodetud element on unikaalne ning projekteeritakse vastavalt kliendi vajadusele.

2. *Tootmisprotsessi ülvaade ning tüüptoodangu valik*

Tootmisprotsessi tüüp on projektipõhine ja teenuse protsessi tüüp on professionaalne. Tootmisprotsess on ehitatud *make-to-order* kontseptsiooni baasil. Selleks, et leida kõige tüüpilisem toode, analüüsiti statistilisi andmeid 2014. aastal müüdud teraselementide kohta (*Sele 4*). Tulemuseks saadi, et enimvalmistatav element on tulekindel siseuks valmistatud SP 35000 profiili süsteemist.

3. *Tootmisprotsessi modelleerimine, aja mõõtmine*

Peale tüüptoodangu valimist järgmiseks sammuks oli kirjeldada olemasolevaid tootmisprotsesse. Kasutades *Smart Draw* tarkvara loodi tootmisprotsessi vooskeem selleks, et defineerida alamprotsesse ning välja tuua terasukse tootmisjärjekord. Kui vooskeem sai valmis, siis määratleti tootmisajad iga operatsiooni kohta. Mõõtmised teostati mehaanilise stopperiga. Võttes arvesse, et tootmise tüüp on projektipõhine, siis oli oluline mõõta aega nii, et tulevikus oleks neid andmeid võimalik kasutada ka teiste toodangute jaoks. Näiteks, mõõdeti igale üksikoperatsioonile kuluv aeg, sõltuvalt kasutatavast profiilisüsteemist ning sulustest. Saadud andmete alusel on lihtsustatud edasine tootmisaja hindamine iga ukse tüübi kohta, vajalik on vaid jagada iga uks tema komponentideks ja kasutada antud töös saadud mõõtmisandmeid iga ukse osa töötlemisaja arvutamiseks ning seejärel need kokku liita.

4. *Olemaoleva tootmisprotsessi modelleerimine, simuleerimine ning analüüs*

Peale algandmete kogumist, loodi olemasolevatest protsessidest *AS-IS* mudel. Selleks valiti *Enterprise Dynamics* tarkvara. Tarkvara võimaldab disainida ja viia läbi mistahes keerukaid simulatsiooni lahendusi seotud tööjõu, masinate või tootimisprotsessi planeerimisega efektiivselt ning minimaalse ajakuluga. Tulemused peale esimest simulatsiooni on saadaval *Selel 17*. Selgemaks tulemuste kirjeldamiseks loodi erinevad graafikud. *Sele 19* ja *Sele 20* näitab tootmismasinate koormatuse jaotust. *Sele 21* näitab iga masina töövõimekust ning toodangute väljundit. Leiti, et tootmine aeglustub käsifreesimise protsessi käigus. Seetõttu tuleks seda protsessi muuta ning “ pudelikael“ kõrvaldada, et üldist tootmisprotsessi parendada.

5. *Terasuste tootmisprotsessi täiustamine*

”Pudelikaela” kõrvaldamiseks, otsustati asendada olemasolevad manuaalsed freesimismasinaid automatiseeritud CNC masinaga. Kõigepealt viidi läbi eelnev CNC masinate otsing. Algselt valiti neli CNC masinat, mis on võimelised töötlema tavalist ja roostevaba terast. Selleks, et määrata, milline masin oleks kõige sobivam, sooritati võrdlev analüüs *Factor-Rating* meetodi baasil. Selle meetodi eesmärk on lihtsustada valikut ja võrrelda omavahel erinevad objekte, võttes arvesse otsuse kriteeriume ja kaalu rakendamist nendele kriteeriumidele. Kriteeriumid olid järgmised: sobiva suurusega töölaua pind, masina võimekus töödelda tavalist ja roostevaba terast, kasutamismugavus, vastupidavus / kvaliteet ja hind (vt *Tabel 9*). Otsuste tegemiseks kasutati 10–pallist skaalat. Peale tabeli täitmist ning parameetrite omavahelise korrutamist, sobivaimaks osutus profiili töötlemiskeskus *SBZ 130 eluCAM*, mis teenis 960 punkti.

6. *Tulevase tootmisprotsessi modelleerimine, simuleerimine ja analüüs*

Peale CNC masina valimist viidi läbi teine simulatsioon, võttes arvesse masina võimekust ning tootlikkust. Tulemuseks saadi, et üks CNC masin suudab asendada kaks manuaal freespinki ja eemaldada järjekordi, mis tekkisid varem. Selle simulatsiooni (*TO-BE*) tulemused on esitatud *Selel 29*. Täiendavad graafikud masinate töökoormusest on saadaval *Selel 30* ja *Selel 31*. Lisaks, selleks, et parandada freesimisoperatsioonide kvaliteeti soovitatakse muuta freesimisoperatsioonide järjekorda. Vastavalt uuele plaanile pakutakse, et kõik operatsioonid, mida on võimalik teostada CNC pingil, viiakse üle CNC masinale ning operatsioonid, mis nõuavad inimese sekkumist ning kontrolli, hakatakse tegema käsitsi. Uus operatsioonide järjekord on kirjeldatud *Selel 28*. Lisaks, et tootmisprotsessi allavoolul asetsev töökoht oleks suuteline töötama samas tempos, nagu CNC operaator, soovitatakse lisada üks töötaja järgmisele töökohale peale CNC töötlemist. Ühtegi töötajat peale protsessi ümberkorraldamist ei tuleks vallandada või juurde võtta, mis kindlasti tõstab töötajate motivatsiooni ning aitab kaasa koostööle.

Tulemused peale protsessi ümberkorraldamist on esitatud *Tabelis 10* ja graafilisel kujul *Selel 33*. Tulemuste põhjal on näha, et tootlikkus on suurenenud 11-st 15-ni tükini ühe 8-tunnise vahetuse jooksul. See tähendab, et igal nädalal on ettevõte võimeline tootma 20 valmistoodet rohkem. Protsentuaalselt on tootmisvõimsus kasvanud 26% võrra.

Tänu CNC pingile ja freesimisprotsessi ümberkorraldamisele, muutus tootmisprotsess sujuvamaks, järjekordade vabaks ja lõpptoode hakkab omama paremat kvaliteeti.

7. *Majanduslik arvutuste teostamine*

Selleks, et selgitada, projekti tasuvusaega, viidi läbi majanduslikud arvutused, mis aitavad ettevõtte juhtkonnal teha otsusi, mis on seotud finantsosaga. Lõputöö raames oli oluline arvutada projekti investeeringu tasuvusaega ja selgitada kaasnevad kulud tootmisprotsessi ümberkorraldamisega. Esiteks, koguti andmeid ja kulud, mis olid seotud

CNC tööpingi ostmisega. Järgmine samm oli arvutada CNC masina tasuvusaega. Täpne arvutus on toodud *Peatükkis 4.2*. Tulemuseks saadi, et CNC masina tasuvusaeg on 1,53 aastat.

Kokkuvõtteks, käesoleva magistritöö käigus kasutati kaasaegseid ja uusi meetmeid rankendades neid terasuste tootmisprotsessi parendamiseks ja täiustamiseks.

Tänu simulatsiooni tarkvarale, õnnestus avastada tootmisliini "kitsaskohad" ja kõrvaldada need, mis tagab tulevikus sujuva tootmise ühtlaselt koormatud töömasinate ja tööjõuga. Lisaks sellele õnnestus tõsta terasuste tootlikkust 26% võrra. Kasutades kaasaegset tarkvara ja saadud kogemust magistritöö tegemisest, on selge võimalus aidata ettevõttel tulevikus tootmisprotsessi arendada, läbi viia projekti käigus välja toodud vajalikud parandused ja simulatsioonid kiiremalt ja minimaalsete kuludega.

Edaspidises töös on mõistlik läbi viia sarnane simulatsioon rakendades seda ka teistele tootetüüpidele ja luua universaalne ning optimeeritud tootmisliin, mis sobib igale toote tüübile ettevõttes Metus-Est AS.

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APPENDICES

Appendix 1. Example of paint layer thickness control sheet

Metus

Värvikihi paksuse mõõtmise kontrollileht

Objekti kood	
Positsioonitähis	
Nominaalne värvikihi paksus	
Kuupäev	

Meetod:
Kuiva värvikihi paksuse mõõtmiseks tuleb võtta elemendilt viiest punktist lugem. Nende mõõtmiste keskmine ei tohi olla väiksem kui nõutud nominaalne värvikihi paksus. Individuaalse näidu värvikihi paksus ei tohi olla väiksem kui 80% nominaalsest värvikihi paksusest.

	Tulemus, μm
Mõõtmine 1	
Mõõtmine 2	
Mõõtmine 3	
Mõõtmine 4	
Mõõtmine 5	
Keskmine	

Nimi:

Allkiri

[12]

Appendix 2. Example of final control sheet

Lõppkontrollileht *(final control sheet)*
Objekti kood *(project code):*
Positsioonitähis *(littera)*;
Kuupäev *(date):*
Nimi*(inspector):*

	Tolerantsid/nõuded *(tolerances)*	**Mõõt/märkused (korras/ei ole korras) *Measurement/remarks (OK or NOT)***	**Meetmed *(counter measures)***
Lengi mõõtude kontroll *Frame measurement check*	+/-2mm		
Raami, lengi ja ukselehtede vaheline vahe *Gaps between doorleaf and frame*	10mm +/-2mm		
Nähtavad pinnad (puhtus, vigastused) *Visible surfaces(cleaness, injuries)*	Värvitud elementi vaadata 2 meetri kauguselt risti pinnaga. Ebakorrapärasusi, mida pole näha, ei käsitleta vigadena *Painted element must be viewed from 2 meters. Defects which are not visible are not calculated as production failure*		
Täidised *Fillings*	Koostatud vastavalt tootejoonisele *Made according the drawings*		
Klaasiliistud *Glazing beads*	+/-1mm profiili tasapinnast. -2mm reaalsest avast *+/- 1mm from profile surface. Up to -2mm in length*		
Tihendid *Gaskets*	Paigaldus ja tüüp vastavalt tootejoonisele P*lace and type according the drawing*		
Sulused (k.a. kaablid ja hinged) *Fittings(included cables and hinges)*	Paigaldus ja tüüp vastavalt tootejoonisele		

	Type of lock according the drawing		
Lukku ei paigalda *Only preparation*	Paigaldada sama või analooglukk/vastus ja kontrollida toimivust *Install and try same or simillar fitting and test opening and closing functions*		
Avanemis- ja sulgumisfunktsioon *Open and closing function*	Kontrollida stendis *Controlled on stand*		
Metuse kleeps *Metus sign*	Üks tükk lengile aktiivse lehe poole *One pcs to the active frame*		
Tulemärgid *Fire classification signs*	Soome igale lehele/lengile, Rootsi üks tükk lengi aktiivse ukselehe poole (u. 1600mm kõrgusele) *In Finland one on each frame and leaf. In Sweden one for every frame on active door side on a height of 1600mm*		
Trossid/kaablid kaablikõris *Wires/cable inside canalisation*	Igas kaablikõris tross/kaabel sees *Every canalisation has wire or cable inside*		

Märkused: Allkiri: ___________________

Remarks: *Signature*:_______________

[13]