TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Mechanical and Industrial Engineering

APPLICABILITY ANALYSIS OF LEAN PRODUCTION TOOLS IN A HIGH-MIX LOW-VOLUME PRODUCTION ENVIRONMENT

KULUSÄÄSTLIKU TOOTMISE TEHNIKATE KOHALDATAVUSE ANALÜÜS SUURE VARIEERUVUSEGA VÄIKESEMAHULISES TOOTMISKESKKONNAS

MASTER THESIS

Student: Martin Hanson

Student code: MARM 192511

Supervisor: Kristo Karjust, Professor

Tallinn 2021

AUTHOR’S DECLARATION

Hereby I declare, that I have written this thesis independently.
No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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Department of Mechanical and Industrial Engineering

THESIS TASK

Student: Martin Hanson, MARM 192511

Study programme, MARM06 Industrial Engineering and Management

Supervisor(s): Professor Kristo Karjust, 6203260

Thesis topic:

(in English) *Applicability analysis of 24 common lean tools in a job shop production environment, further analysis of select tools, simulation and effect calculation.*

(in Estonian) 24 enam levinud kulusäästliku tootmise tehnikate kohaldatavuse analüüs tööpoe keskkonnas, süvaanalüüs valitud tehnikatele koos simulatiooni ja nende mõjuarvutusega.

Thesis main objectives:

1. Company, production and business environment overview with internal and external strategic factors.

2. Overview of more common lean tools and their applicability in a job shop environment.

3. Select tools analysis, potential benefits and drawbacks, calculations of their effect.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Thesis task formulation and initial plan	02.03
2.	Business environment and strategic factors analysis	20.03
3.	Lean tool selection matrix and analysis of applicable tools	01.05
4.	Implementation plan and economic calculations	15.05

Language: English **Deadline for submission of thesis:** “26” May 2021a

Student: Martin Hanson ………………… “…….”…………………………….20….a

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PREFACE

The subject and topic of the thesis was formulated by the author with help from supervisor, Professor Kristo Karjust. The main data, analysis and simulation for the thesis were taken from the company Alas-Kuul AS.

I would like to thank Alas-Kuul's employees who helped with inspiration and consultation. In addition, I would like to thank Mr. Kristo Karjust, my supervisor, and Annela Hendrikson, mother of my son, for their continuous support.

This thesis investigates the applicability of different Lean tools and techniques in a job shop environment, where most of the products are unique. Company analysis with insight into its processes, production, business environment and strategic factors are analysed, which are all input for selecting lean tools which will be further analysed, tested, simulated and their effect calculated.

Keywords: Lean tools; Job shop; High-mix low volume; Tailor-made products, Master's thesis.

1. INTRODUCTION

The main objective of the thesis is to analyse and investigate the applicability of different Lean management tools in a production environment, which consists of a high degree of different products with low volumes.

Lean philosophy is well known in high-volume standardised productions, where process control and optimisation are a proven tool to find and reduce wastes. Originally named as Toyota Production System, Lean has evolved over time as a philosophy used not only in production but in all processes and operations of an organisation. With sustainability and efficiency requirements high in every production sector and natural resources decreasing and becoming more expensive, reduction of waste and non-value-added activities is a logical step for an organisation to increase its competitiveness [1].

The objective of this thesis is to analyse if Lean tools could be used in a job shop production environment, where customer specifies the products characteristics with every order and there are no standardized end products. Such an environment poses several difficulties for lean philosophy, which is mainly used to optimize the processes with high repeatability. As the general movement of less wastes and higher efficiency is the same for job shops, this thesis analyses if and to what extent could lean tools be used, how difficult it would be and what would be the potential advantages or disadvantages [1].

The environment in which this thesis is based on is the Minitec tailor made solutions department of an industrial sales and service company Alas-Kuul AS. Minitec is an aluminium profile system, offering wide range of possibilities to construct different custom solutions depending on the specifications of the customer. Overview of the company, the products, the production environment, operations, business environment and strategic factors will yield the criteria that will be used for appropriate lean tool selection. The more popular Lean tools will be analysed in the Lean tool matrix with appropriate weights and ratings to each tool. The tools with the highest ratings will be selected for in-depth analysis to understand their applicability and potential benefits. Based on the analysis, changes and improvements to the current processes are proposed, simulated and their cost and benefits in time and value are calculated. The last part is the implementation with overview on employee engagement and motivation, implementation plan of the selected tools and updated KPIs to monitor and measure the effects of improvements [2].

2. IMPORTANCE OF LEAN

What is known today as Lean management is a philosophy that originates from Japan, having its roots in 1920s and was developed as Ohno Production System in the 1950s (later widely known as Toyota Production System) by Taiichi Ohno. In the time where Ford produced huge numbers of limited models, Toyota needed to produce low volumes of different models which meant investment for a large assembly line for one type of model was not reasonable. The market for Toyota models was low so the resources to use were limited. The limited number of resources is the reason Taiichi Ohno had to find tools to produce quality products in small numbers with short lead-time and high flexibility. Overproduction was one of the largest wastes that Taiichi needed to abolish as it would create large inventory and having finances tied under inventory might have been the end for Toyota. This environment of limited resources is what compelled the development of the Toyota Production System [1].

Lean term itself was coined decades later in America after Toyota created join venture with GM and showed unbelievable improvements in the joint production. After the world war and up until 1970st material and resource were an abundance and thus waste were not as important issue. Only starting from 1980s when the cost of material and workforce rose fast, it was discovered how running your production the Toyota way or „lean" would make the company more competitive and improved quality. At that time, it was considered a philosophy mainly for larger companies with high overhead costs [1].

Fast forward to today, the ever-costly material and human capital plus sustainability and green thinking for environment has become extremely important, giving a company the leading edge not only in production and processes but also in marketing for customers. This makes Lean philosophy in production critical to remain in competition, please customers' environmental awareness and comply to environmental regulations. While Lean is mostly used in productions with high volume in a limited number of different products to reduce wastes, increase flow and standardise, early development of Lean was for lower volume and larger mix of products, showing it could be applicable to an extent in a job shop layout too [1].

3. COMPANY AND BUSINESS ENVIRONMENT

3.1 History of Alas-Kuul

Alas-Kuul was created in 1993 with the purpose of sales and service for ball bearings. Most of the bearings used at the time came from Russia and were manufactured according to the GOST quality standard. The quality of bearings produced in Europe were with superior quality and thus the owner of Alas-Kuul Mr. Indrek Orro decided to start selling the bearings produced by SKF. Adding different other products to the mix according to the industry needs in Estonia, Alas-Kuul has grown to be one of the largest industrial service companies with annual revenue of 20 000 000 euros (see Appendix 1). Today the product mix is very wide and for a simplified overview can be classified into six main categories, of which an overview is given on figure 3.1 [2].

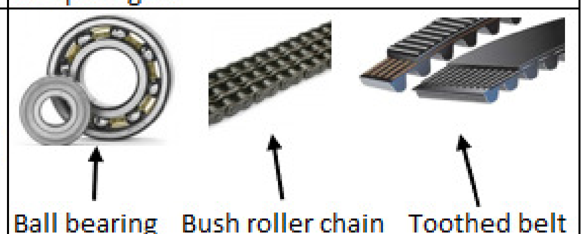
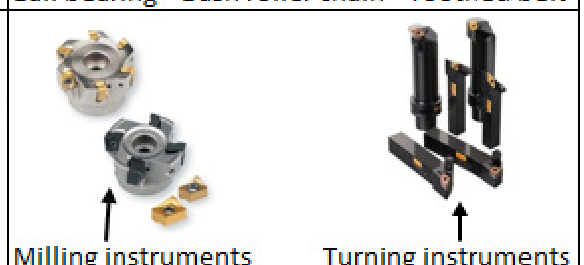
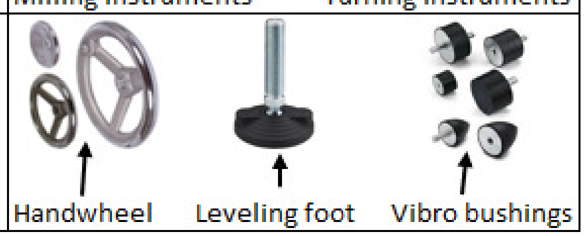
Group	Includes	Sample figure
1. Small grade wear parts [2, 3]	Bearings, chains, belts, sealings [2, 3]	
2. Metal cutting instruments [2]	For milling, turning, sawing, threading [4, 5]	
3. Industrial components [2, 6]	Handles, leveling feet, rollers, linear guides, lead screws [6]	

Figure 3.1 Alas-Kuul's main product categories [2, 3, 4, 5, 6]

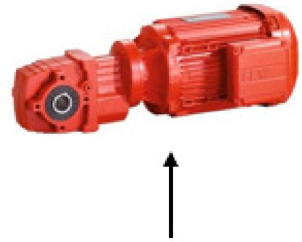
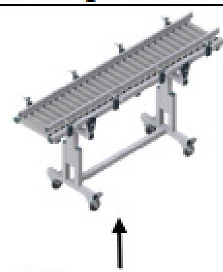
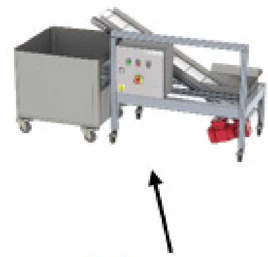
4. Drives and Motors [2]	Electric motors, gearmotors, frequency inverters and converters, roller drives, pumps [2, 7, 8]	 Frequency inverter  Gearmotor
5. Standard equipment and machines [2, 9, 10]	Welding equipment and machines, welding robots, compressors [2, 9, 10]	 Welding machine  Screw compressor
6. Custom machines/tailor made solutions [2, 11, 12, 13]	Conveyors, working tables, linear systems [2, 11]	 Roller conveyor  Belt conveyor

Figure 3.1 Alas-Kuul's main product categories [2, 7, 8, 9, 10, 11, 12, 13] continued

Custom solutions and machines are one of the latest additions when around 2017 after acquiring the selling rights of aluminium profile system by Minitec GmbH, management decided to start offering the customers assembly of different frames and aids according to their needs. In 2019, new separate building was built to house the larger space needed for assembly production and by today, it has grown to be a business of about one million in revenue. This is the product group that forms the basis of this thesis and where the analysis and simulations are conducted [14, 15].

3.2 Tailor-made product

The benefit of building from aluminium profile system is flexibility – there is a wide selection of profiles depending on the strength and need of the final solution. The extruded profiles arrive as 6-meters long bars and are cut to required dimensions thus allowing to create tailor-made products with exactly the measures currently needed. The selection of components is wide, ranging for several different connection possibilities to linear system, ready-made specific components for belt and roller conveyors, working tables, safety fences, machine frames etc. There is already a sense of Lean philosophy in Minitec aluminium profile system – the profiles allow to create exactly what is needed and are reusable, consisting of special parts for Kanban tables etc. An example of tailor-made solution can be seen on figure 3.2, which depicts a mobile product buffer conveyor, which conveys fallen products from processing machine to a higher conveyor. [15].

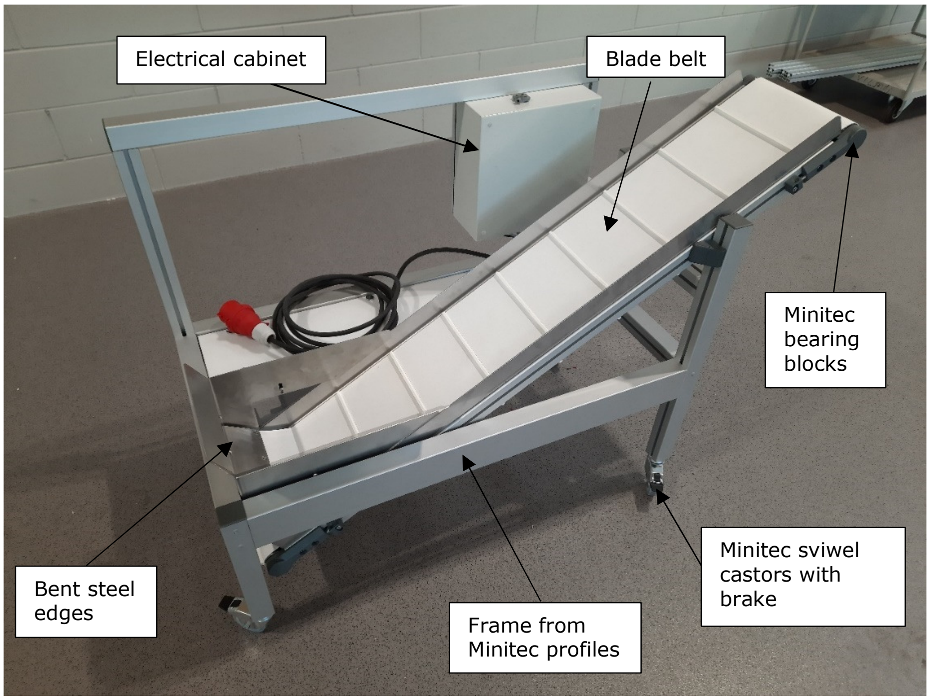


Figure 3.2 Mobile product buffer conveyor with sectioned belt [15]

When this department started in 2017, it quickly saw added value in incorporating other Alas-Kuul's key suppliers with solutions made with Minitec – mainly SKF bearings, SEW electric motors and HIWIN linear technology [2].

SKF is very well known in the local market for different kinds of bearings, for example deep groove ball bearings, cylindrical and spherical roller bearings, thrust ball bearings and so on [2, 3].

SEW is a well-known quality brand when it comes to electric motors, gearboxes, frequency converters etc. and are already well known in the market as good value for money. Using SEW's products in conveyors and linear technology adds value to the end solution as being a quality product [2, 7, 8].

Hiwin is specialized in linear technology with a wide array of solution including linear guides and guideways, ball screws, linear- and servomotors etc. While Minitec also has linear guides in their product assortment, they cannot withstand higher loads and speeds and Hiwin fills that void [16].

To sum up, the product range is from simple aluminium profiles and components to tailor made conveyors and working tables up to plug and play stand-alone or integrated processing machines.

The potential market is all industrial productions excluding food and beverage sector (as they mainly use stainless steel in construction and components) and customers with medium to heavy products (single product weight of over 50kg). Alas-Kuul's main customer base today is mainly from other machine building and engineering companies or timber and electronics sectors [14].

3.3 Production site overview

In the production, the used process type is job shop – as the products are low-volume high-variety and the processing is intermittent, it consists of several smaller jobs with different processing requirements depending on the customers specification for the order. This kind of process type needs skilled workforce who can work with different machines and are not trained to operate just one process or activity [17].

The advantages of this layout are:

- the ability to handle wide variety of work as the workforce is skilled and there are several general-purpose machines;
- The fixed costs are low because of high flexibility and general-purpose machines [17].

The disadvantages are:

- high cost per unit as the number of similar products at once are low;
- high variable costs as the total number of products are low (nothing is mass-produced, even batches are single-digit);
- complex planning schedule because of very high variety of processing times and no forecasted running products [17].

The process layout (also known as functional layout) is used since the processing is nonrepetitive and the workflow is discontinuous. Items that require processing are moved in one production order at a time, material handling equipment used are purpose-built large tables (that are also used as workstations for lighter assembly) that are manually moved in the production, from machine to machine, as can be seen on figure 3.3 [17].

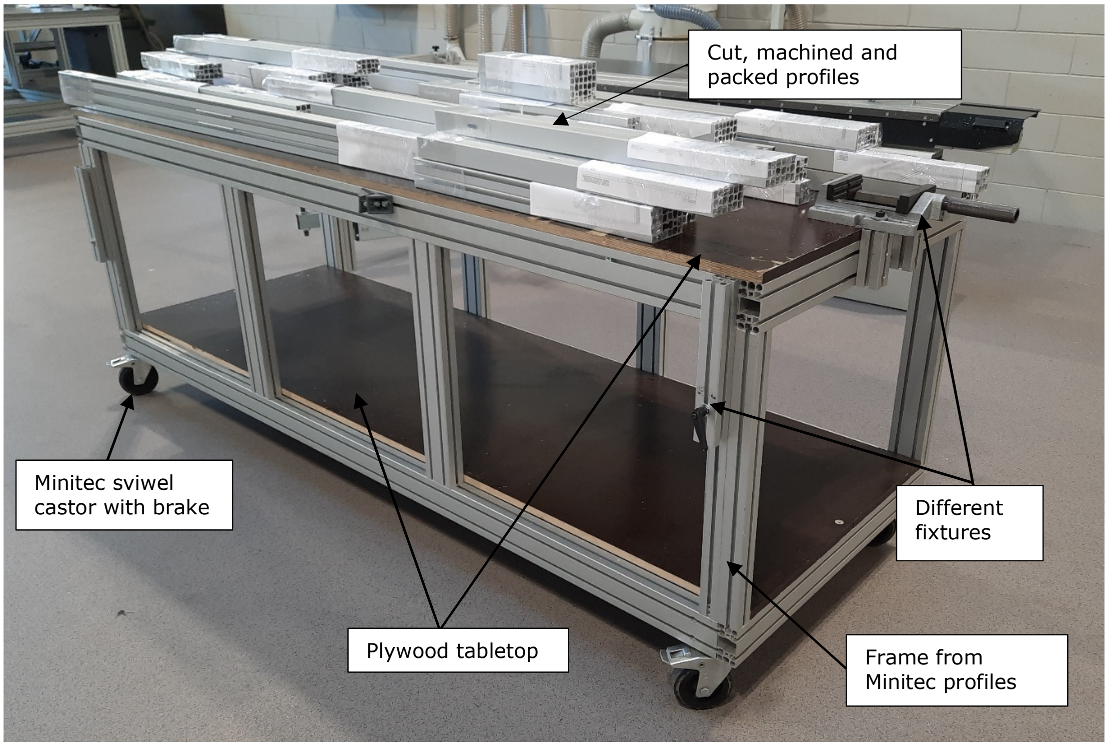


Figure 3.3 Material movement and assembly tables

The advantages of process layout are:

- High flexibility in terms of product and processing requirements;
- Less vulnerable to machine shutdowns by mechanical failure – other machines or other processing requirements can be done and products/orders will not accumulate in upstream processes waiting;
- General-purpose equipment is less costly to buy and maintain, also skilled workforce can do small repairs on site fast [17].

The disadvantages to process layout are:

- Purchasing, planning, inventory control and scheduling are difficult and requires constant involvement to manage flow successfully;
- Equipment/facilities utilization is low;
- Material handling is slow and inefficient, resulting in higher cost per unit;
- Can have a high work in process (in Alas-Kuul's case depending on the size of one production order) [17].

The shop floor consists of three larger rooms and is influence by the location of entrances: 1st room has large entrance for loading and unloading trucks with 6-meter profiles stocked next to the profile saw on one side and guides stock with guide saw on other side (see Profile and Guideway saw under Graphics). 2nd room features all the processing machines to keep them away from forklifts on the first room. The processing machines in the room are format saw, drilling machine, milling machine, turning machine, threading drill, polishing machine and fixed tool tables (see Shop floor, Drilling machine and format saw and Milling and turning machine under Graphics). 3rd room is mostly used for assembly and packing and it features the component stock. The second floor comprises of meetings room, kitchen and work area for sales and design.

Depending on the production orders and current machine utilization, employees can choose the process sequence with some limitations:

1. Cutting will always be the first process as uncut 6-meter profiles cannot be moved around due to size (except in very rare cases when customer buys the whole bar without further processing needs).
2. All machining processes must be done before assembly – partly assembled parts do not fit to processing machines and in many cases, it is more difficult to process.

In terms of human capital in this department, table 3.1 will give an overview of key personnel and their respective assignments:

Table 3.1 Department personnel overview

Position	N. of people	Job description
Sales Engineer	2	Daily sales with extra steps on consulting customers on which components to use in which cases, designing simpler solutions in CAD programs, managing projects. Can back up production workers.
Sales Assistant	1	Administrative work with offers and orders that consist only of parts and components, no assemblies.
Designer	1	Consulting customers and working full time with Solidworks to design and create more complex solutions for customers and working drawings for production workers. Can back up production workers.
Production workers	3	Machining, compiling, assembly and packing of orders according to BOM or technical drawings. One production worker is qualified in electrics and compiles the electric cabinets.

The simplified process sequence can be seen on figure 3.4, where the main process interactions between customer, sales and production can be seen. As usual, the process starts with customers enquiry or need to which sales department replies with an offer (if it includes more complex assemblies, designer is used for price assessment). When the customer accepts the offer, it will be registered in the system and in case of a simple order, it will be printed and put on order wall in the production while system automatically creates requirements for articles which are either purchased right away or in case of Minitec, on every Friday. If the order is more complex, designer will draw the 3D model and it will be confirmed by customer before starting the production process. This is followed by the activities on the shop floor and finishes with final inspection, ordering transport by the production worker and invoicing the customer by the sales. Depending on the need, this process can have small varieties to keep the system flexible [18].

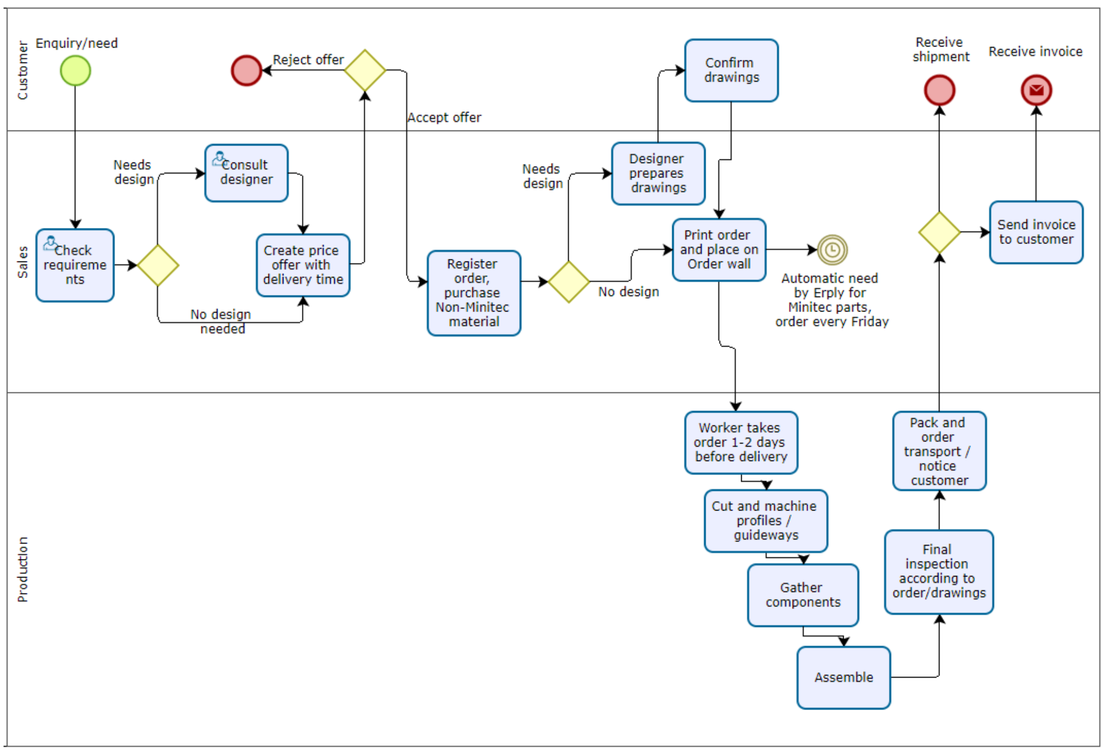


Figure 3.4 Simplified process map from customer enquiry to receiving shipment [18]

3.4 Operations management and performance

Four characteristics of customer demand have a critical effect on how operations and processes should be managed. Analysing them from the point of Alas-Kuul, these four characteristics are:

1. Volume – low-volume processes have less repeatability and thus standardisation and specialisation cannot be used to the same extent as in case of high-volume processes. Workers need to be able to perform wider range of tasks and thus are more flexible, but processes are less open for systemisation and are not as efficient.

2. Variety – high-variety processes are more costly and complex than low-variety processes, but it will match customers' needs to a higher degree.
3. Variation – High demand variety requires production to be very flexible to changes in capacity needs and scheduling is difficult.
4. Visibility – Custom made products' visibility is medium as the specification is agreed upon mutually, requiring flexibility and will translate to high unit costs [19].

The four V's show that management's focus should be kept on trying to reduce already high unit costs and keeping in line with changes in customers demand by high flexibility [19].

A successful organisation needs to use its resources effectively to produce products and services that satisfies the customer. This would mean a more competitive organisation with reduced costs and higher revenue, translating to higher profit. To that end, five operations performance objectives which an organisation should continuously work on to improve are:

- Speed – Minimizing the time between customer order and delivery to customer;
- Quality – Providing error-free goods for the customer;
- Dependability – Keeping the delivery promises made to the customers;
- Flexibility – Ability to adapt to varying customer requests;
- Cost – Producing goods and services at a cost that is profitable and according to market expectations [19].

As a job shop, Alas-Kuul's flexibility is already high within the limit of the machines and more skilled production workers. Quality problems are low thanks to job-shop specific nuances – there is no accumulation of products as volumes are low and since products vary to a high degree and are produced according to changing specifications, they already require a high attention to detail every time, greatly minimising mistakes that routine work creates. So Alas-Kuul's effort should be directed towards speed, dependability and cost to be more competitive: Speed because material handling is slow and inefficient; Dependability because of complex scheduling and planning; Cost because of high variable cost and cost per unit. In terms of Lean tools value stream, wastes and scheduling should be analysed for potential improvement [1, 17, 19].

3.5 Market overview

A view on manufacturing by Statistics Estonia's TO001: Industrial production at current prices by economic activity [20] shows gradual increase from 2005 to 2017, where in some of the sectors the manufacturing volume has doubled. For example, the manufacture of machinery equipment has increased from 156.5 to 394.9 million euros per annum, electronics industry has increased from 307 to 1305 million euros per annum. Manufacture of machinery is the main sector Minitec is suitable for while the electronics sector is the main customer for these machines manufactured either by Alas-Kuul or Alas-Kuul's engineering customers. Although the recent quarter analysis shows a decline due to pandemic, long term view shows a very fertile market [20].

Furthermore, looking at the latest preliminary annual data of 2019 by Statistics Estonia – Trade, manufacturing and information and communication enterprises contributed most to the increase, with negative effect coming from mining and energy. In 2019, enterprises sold goods and services 5% more than 2018 and although the labour productivity rose 3%, labour costs itself increased by 9%, confirming the continuing need to invest in machinery to keep labour costs rise at bay. Enterprises invested 3.2 billion euros, a 20% increase from 2018 with most of the investments going into machinery, equipment and buildings. The larger view for the last decade shows the faster growth of business sector between 2010 and to 2013 with a pause and a marginal decline between 2014 and 2017 after which it turned back to stable growth (see table 3.5), showing a stable and positive trend of Estonian business macroeconomics [21, 22].

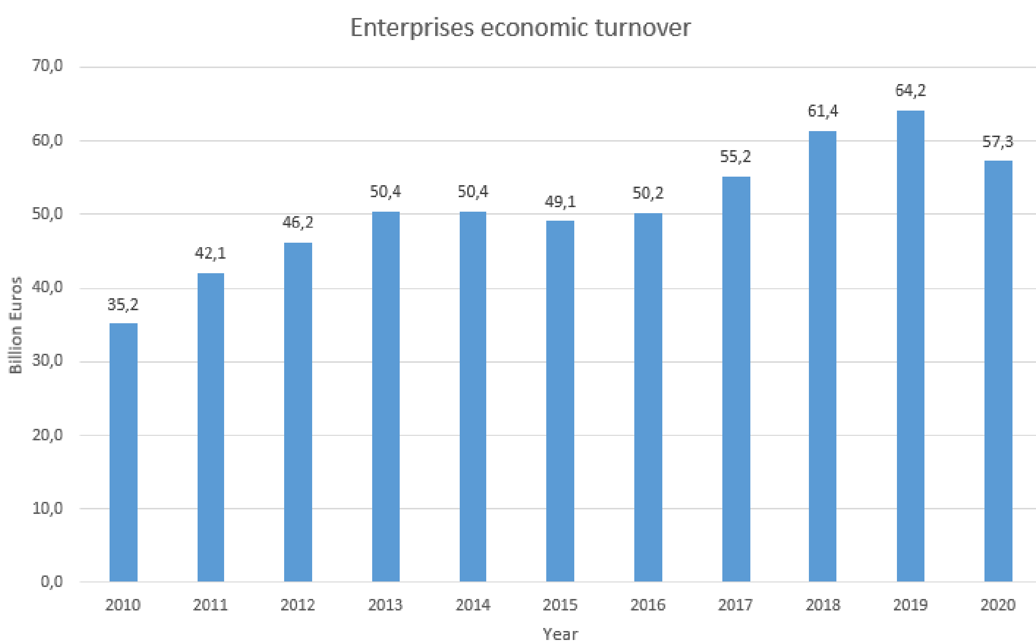


Figure 3.5 Business sector turnover increase in the last decade [22]

Although the effect from coronavirus pandemic is not yet finalized, figure 3.6 shows the decrease of turnover due to pandemic in 2020 was only around 11% compared to 2019. Considering the overall lockdowns and uncertainty, the similar level can be expected from 2021, but with vaccinations to public underway, the economy should turn back to growth. According to annual report from appendix 1 and overview of Minitec department in appendix 2 and 3, Alas-Kuul's and Minitec department's revenue decrease was about 12% for the whole company and around 30% in Minitec department compared to 2019. It is expected to turn back to growth after the effects of pandemic are contained and customers continue the paused investments [20, 21, 22].

3.6 Company's business strategy

To analyse how the company's product, production and processes affect their business strategy and where should improvements be directed, the inputs of SWOT (Strengths-Weaknesses-Opportunities-Threats) matrix will be used: Internal and external factors. The internal and external factors will be compared with their respective weight (importance) and rating (estimated level), which will give a weighted score and help to identify the most important points for optimisation. The value of weight per matrix is 1.00 divided between different factors. The ratings will be given according to authors assessment in a scale of 1 to 5, with 1 meaning the factor is not applicable and 5 meaning it is critically important. Two main factors of each category from internal and external factors will be highlighted as bold text [23].

Table 3.2 Company's Internal Factors [23]

Internal factors	**Weight**	**Rating**	**Weighted Score**	**Comments**
Strengths				
1. High product flexibility	0,16	4,00	0,64	Minitec profile system provides high flexibility for tailor made solutions
2. High-quality supplier mix	0,07	3,00	0,21	Minitec, SEW, Hiwin etc. are all European producers
3. Strong financial status	0,12	2,50	0,30	Companies' financials are strong
4. Strong position in market, well known company	0,11	3,00	0,33	Has been in the market for 25 years, helpful in sales

Table 3.2 Company's Internal Factors [23] continued

Internal factors	Weight	Rating	Weighted Score	Comments
Weaknesses				
1. Low efficiency of machines and material handling	0,08	3,00	0,24	Low possibility for standardisation
<u>2. Difficult to respond to demand changes</u>	0,12	4,00	<u>0,48</u>	No forecasted products
<u>3. High unit cost</u>	0,20	4,50	<u>0,90</u>	Low efficiency makes final product expensive
4. High work-in-process	0,08	2,00	0,16	Depends on order size
5. Company is mostly known as a sales company	0,06	3,00	0,18	Minitec solutions department young in terms of company's age
Sum	1,00		3,44	

The two factors from each section with the highest score are underlined.

As a result of analysis, the company's main strengths are high product flexibility thanks to quality suppliers and a strong position on the market as a known company for industrial services for over 25 years. The main weaknesses are difficulty to respond to demand changes and a high unit cost (see table 3.2, the two factors with highest score are underlined) [23].

Table 3.3 Company's External Factors [23]

External factors	Weight	Rating	Weighted Score	Comments
Opportunities				
<u>1. Market demand for specialized machines rising</u>	0,19	3,00	<u>0,57</u>	More often customers need a special machine or to upgrade an existing standard machine
<u>2. Customers want to build themselves</u>	0,14	4,00	<u>0,56</u>	Thanks to Minitec's modular philosophy
3. Some sectors booming	0,08	2,50	0,20	e-business, food, medical
Threats				
<u>1. Main competition is standard machines with lower price</u>	0,17	3,00	<u>0,51</u>	Wide selection of machines in EU with lower prices than custom made
2. Global economic downturn due to Pandemic	0,12	4,00	0,48	Decreased investments & sales
3. Products from China	0,08	4	0,32	Wide selection of half-automatic machines from China with low price
<u>4. Threat of substitute products high</u>	0,22	3,5	<u>0,77</u>	Several additional profile system producers could expand to Estonia
Sum	1,00		3,41	

The two factors from each section with the highest score are underlined.

The analysis indicated that the company's main opportunities are a rising market demand for specialised machines and growing interest in customers to build the needed solution themselves (which Minitec permits without the use of wide arrange of special tools like welding etc). The main threats the company is facing are the main competition from standard machines and their lower prices thanks to shared R&D costs and higher efficiency in production and the threat of other similar profile systems in the market, further elaborated in table 3.3 [23].

Analysis into internal and external forces show the main strengths and opportunities for the company to use for success and grow, which are mainly flexible product mix and a favourable market tendency. The weaknesses and threats align with performance objectives to improve: speed in trying to respond to demand changes, lowering the cost, increasing dependability to be more competitive [19, 23].

3.7 Shop floor inspection

After analysis of the business environment, shop floor and order process has been inspected for several weeks to have an overview how things run daily. The shortcomings that came up on day-to-day operations are:

- No documented value stream map, only a pull system is used according to customer orders, thus it is hard to assess the costs and value the customer is buying exactly and which services are more or which less profitable;
- Scheduling is done by visual inspection and educated guess – production orders are on a physical wall sequenced by departure date and workers choose and take the production order according to the date. This leads to periods with uneven levels of work. Since a production order can take one hour or weeks to complete, scheduling is difficult but critical;
- Dependency problems – while most production orders take from two to six hours to complete, some orders can take more which is realized while order is in process. This is especially so with orders that do not contain assembly operation, just cutting, drilling etc. Visually, it is hard to evaluate how much time an order takes and when should it be started to meet the departure deadline at 3pm every working day. This problem is two-fold – production people struggle to keep the deadlines while sales engineers struggle to understand how much resource they have left to sell for a specific date;
- As the profile is sold at specific lengths and they come in as 6-meter bars, the leftover profiles must be used to maximum to minimize material waste. As the

leftover material shelves are not organized, the time it takes to shuffle through them is highly variable;

- Lack of KPIs – this department has developed fast with just 3 years and the number of employees has tripled, but the main software used daily is focused on material and inventory planning. This means there is a lack of measurable KPIs besides sales and stock value to understand the current state and to see changes and development over time.

4. LEAN TOOL SELECTION

The strategic analysis of the company, the shop floor and the business environment has given specific inputs on which subjects need improvement so that Lean management tools could be targeted effectively and precisely. Since Lean management as a philosophy is new for this production, it is vital to start with targeted incremental changes so that improvements would be visual and thus motivating the employees to embrace the culture change.

4.1 Job Shop vs Assembly line

Before starting to apply lean tools, it is educative to pause and see the several key differences between a job shop setting and an assembly line that is in a batch or mass production, which limits and changes how and where to apply Lean. The most significant differences are:

- Manufacturing routings differ significantly due to high volume of different processing needs and shifting bottlenecks while order repeatability is low;
- Demand variability is high with little to no possibility of forecasting;
- Production plans are driven by due dates and processing times differ from hours to days, meaning production scheduling and control are complex;
- Diverse mix of products, machines and processing requirements demand workers with higher skills who are cross trained to use different machines [17, 24].

The most outstanding problems are with scheduling and costs – first one very common in all job shops and second one common in all production types, so the problems being faced are very common [24].

4.2 Lean implementation process in job shop

Let us have a look at the classic process of implementing Lean and differences of job shop with possible analogies, further visualised in figure 4.1:

1. Identify value – specify value from the customers view. Due to large number of products and components the amount of value streams would be very large and constantly changing. One possibility is to gather parts with similar processing needs and analyse their value stream.
2. Map the value stream – Identify the steps in value stream and eliminate the steps that do not provide value. Problem from point 1 continues, it would require mapping order flows that might not repeat. In job shop the possible solution is

to map a value network – listing all the possible processing machines a production order could go through. Now it is possible to analyse part families with similar processing requirements with value network map as an input.

3. Create flow – The product should flow smoothly towards the customer. Continuous flow only works in assembly lines where the idea is to break down the batch into continuous flow of individual parts. Upside here is that in job shops, orders are usually processed one at a time, resulting less work-in-process and waiting compared to batch or mass production.
4. Establish pull – Let the customer pull the product though value stream. Fortunately, this is how a job shop generally works – products are all made-to-order according to customers' orders instead of made-to-stock.
5. Seek perfection – rework the value streams to eliminate waste and improve processes [1, 24].

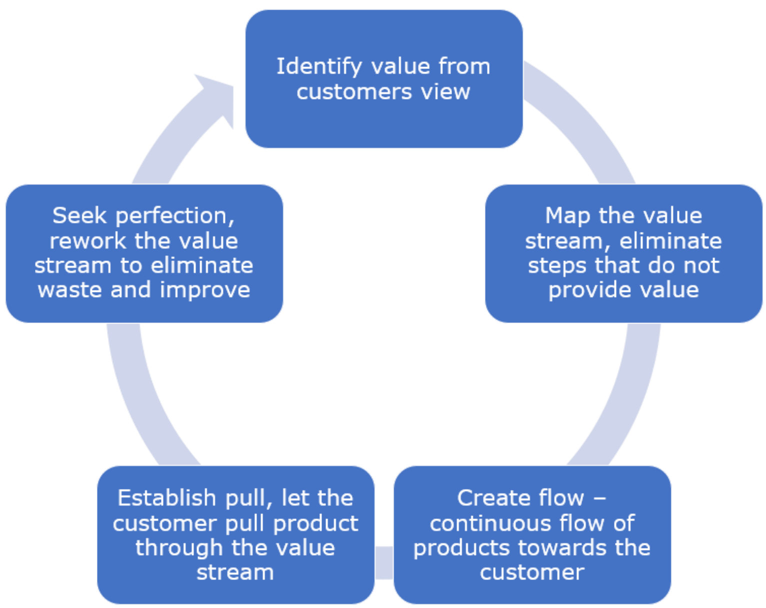


Figure 4.1 Classic Lean implementation framework [24]

Mr. S.Irani [24] recommends to develop autonomous cells (as in cell manufacturing layout) and to use group technology, so that each cell would work as their own production. In this case it is possible to create a cell's value streams opening possibilities to further improve and eliminate wastes. While this is a very good idea, it applies to medium to large companies with several of the same type machines, but in case of a small production, where there is one or few of each machine, this is hard to achieve [1, 24].

4.3 Lean tool criteria and selection

The Lean tools to be analysed and tested should be applicable to job shop environment and aligned with the strategic goals of the company. The criteria for which Lean tools should have positive improvement towards are:

1. Cost/value – which are the value-added and non-value-added activities, how to reduce cost of producing without sacrificing quality and flexibility?
2. Speed – for competitive edge, to deliver solutions faster than competition while not increasing costs or decreasing dependability;
3. Dependability – for competitive edge, to deliver on time and according to customer specification without increasing cost or speed [19].

In the lean tool selection matrix on table 4.3.1, weight is the projected effect this lean tool has on the criteria on a scale of 0.00 (none) to 1.00 (most important). Total weights must sum to 1.00 regardless of number of tools. The tools are the most common ones found in different books and publication about lean chosen by the author, the applicability is the result of analysis inside Alas-Kuul. Rating is the perceived applicability and effect of the tool on Alas-Kuul's environment. Rating is on a scale of 0 (not applicable/no effect) to 5 (Most applicable/very large effect) [1, 23, 24, 25].

Table 4.1 Lean tool selection matrix [1, 23, 24, 25]

Tool	**Criteria**	**Weight**	**Rating**	**Total**	**Applicability**
Value stream mapping	Cost	0,100	4,50	0,45	First step to understand where value is created and how cost and price develop
Scheduling (heijunka)	Dependability	0,075	4,00	0,30	As job shop production is very intermittent without forecasts and repeatability, scheduling level will determine delivery precision
8 Wastes: Transport		0,030	2,00	0,06	Without increasing inventory, only small reductions could be achieved as demand cannot be forecasted
8 Wastes: Inventory	Cost	0,060	4,00	0,24	Large inventory keeps finances tied and needs space
8 Wastes: Motion	Cost & Speed	0,040	4,50	0,18	Due to lack of conveyors and automatic movements, motion is slow in job shops
8 Wastes: Waiting		0,050	2,00	0,10	Can be an issue in a job shop environment but usually not as critical since it is a project based with more flexible delivery times

Table 4.1 Lean tool selection matrix [1, 23, 24, 25] continued

8 Wastes: Overprocessing		0,040	1,00	0,04	In tailor made solutions, overproduction depends on design and is seldom an issue
8 Wastes: Overproduction		0,040	1,00	0,04	In a job-shop or made-to-order production, overproduction is not an issue as it is a pure pull system
8 Wastes: Defects		0,030	2,00	0,06	Due to high variety, processing is usually done by technical drawings, greatly reducing production defects
8 Wastes: Unused potential	Cost, Speed & Dependability	0,050	4,00	0,20	More important in job shop compared to other production layouts as it needs more skilled workforce who must adapt and be independent
5S	Cost & Speed	0,080	4,00	0,32	Sorted and standardized workplaces reduce total product cycle time
SMED		0,040	2,00	0,08	In the case of Alas-Kuul, the technical setup of machines is short, the longer setup time in general is more related to 5S
Just-In-Time		0,030	1,00	0,03	Job shop generally works in the confines of just-in-time - the made-to-order systems works by just-in-time pull system
Continuous Improvement (Kaizen)		0,040	3,50	0,14	Although important to turn an organisation into continuously improving one, the start of Lean is too early for this and should be considered after some successful implementations
Poka-Yoke		0,020	1,50	0,03	Difficult to create fool-proof systems in an environment, where every order is considered as prototype
Andon		0,010	1,00	0,01	Mostly not applicable to job shop, especially smaller productions where worker handles one order from start to finish
Kanban		0,020	2,00	0,04	Is a difficult tool to start from, especially without forecasted standardized products
Continuous (one-piece-) flow		0,030	1,00	0,03	Not applicable in job shop, would create huge scheduling problems as there are no standard routings
Jidoka		0,020	1,00	0,02	Hard to implement in manual labour heavy environments
Visual factory	Dependability	0,020	3,00	0,06	Will be implemented as part of Scheduling and KPIs
Bottleneck analysis		0,040	2,00	0,08	Bottleneck analysis can point some constraints at the system, but to analyse it, scheduling must be at a high level, otherwise we cannot differentiate from scheduling and bottleneck problems

Table 4.1 Lean tool selection matrix [1, 23, 24, 25] continued

OEE		0,040	1,00	0,04	In job shop environment flexibility is more important that OEE, mostly because production order processing needs differ to great extent
PDCA		0,050	3,00	0,15	Could be considered after the initial implementation when Lean is more grown into the organisation
TPM		0,045	2,00	0,09	Useful but not as critical as the processing machines used are fairly standard and thus maintenance and repairs can be done by employees
Total scores		1,000		2,79	

The tools with the highest score chosen for further analysis are underlined.

The analysis and lean selection table's weighted scores indicated the tools with largest probability on improving cost, speed and dependability in Alas-Kuul's case are:

- Value stream mapping – to understand where value is created and which processes do not add value;
- Scheduling – deriving from deficiencies on the shop floor, for better managing on resources and highly variable demand;
- Inventory waste – High variety in product demand can cause large inventory;
- Motion waste – As job shop has no automated material movement, this is a vital waste to further investigate;
- Unused potential – deriving from the notion that job shop needs skilled workforce compared to other process types;
- 5S – Large variety in processing can cause a lot of tools and material around workspaces [1, 23, 24, 25];

In the following chapters, these Lean tools will be analysed in depth.

5. VALUE NETWORK MAPPING

5.1 Operation cycle times

Before starting with lean analysis, some KPIs are needed to act as basis to know and measure changes/improvement. To get the cycle time, 10 cycle times were measured together with setups/changeovers to get an average result. The reason for this is the variety of cycle times due to different characteristics (profile size, angle vs straight cut, size of hole etc.). As average or median time shows the cycle time where 50% are longer and 50% are shorter, this could lead to delays as several longer cycle times happen in consecutive order. For that reason, 75th percentile was chosen instead of mean, showing the cycle time of 75% of the time, leaving out 25% of the largest deviations [26].

5.2 The value in product

To define the value, the first step is to define the product customer wishes and work backwards through value stream. In Alas-Kuul's case, the product configuration varies by a large margin, but the general values customer seeks and pays for are:

- technical consultation and specification of the final product (design and drawings);
- the raw material, which in this case is aluminium profiles and components;
- machining and assembly;
- packing and transport from the production site to customer's site.

All the activities that do not constitute as above are not providing value to the customer and are either non-value adding or business-value adding (needed to keep the business successfully running) [25].

5.3 Value network map

Usually, value stream maps are done by tracking a specific product's flow through the system to see all the actions that add value and the ones that do not. In job shop case, there is no specific product, so the value stream can be based on the available processes and their respective cycle times. By documenting the average process times per piece with value-added and non-value-added times it is possible to get an overview of the time and resources customer pays for and waste. This means the goal is to improve processes themselves and such improvement will translate to improvements on whichever product is worked on [24].

Below is the value network map for the Minitec department's production environment. The cycle times are calculated 75th percentile averages from real time measurements of 10 process times per piece (except for packing, which is per order). The network starts with purchase order to supplier, that delivers the parts with usual lead time between one and two weeks. Since some of the high-runner components and profiles are held in stock, the lead-time at the point of order release can be from 2 working days to 10 working days. After material and component stock all possible processes are listed with their respective cycle and changeover times that could be used in case of a large project. In real life only some of the processes on the bottom line are used – the order can consist of only releasing full length aluminium profile from stock straight to packing and delivery to customer and in many cases just from guideway saw to packing and delivery. In many cases cutting and some extra machining is required as drilling or threading. The material/component stock are listed as separate entity for the purpose of illustrating the stock in terms of material and component releasing times, these are calculated into the changeover/cycle time since every production worker acquires the material himself before a specific process (no designated person for material release), as can be seen on figure 5.1. The full operations timing table can be seen at appendix 4 [24, 26, 27].

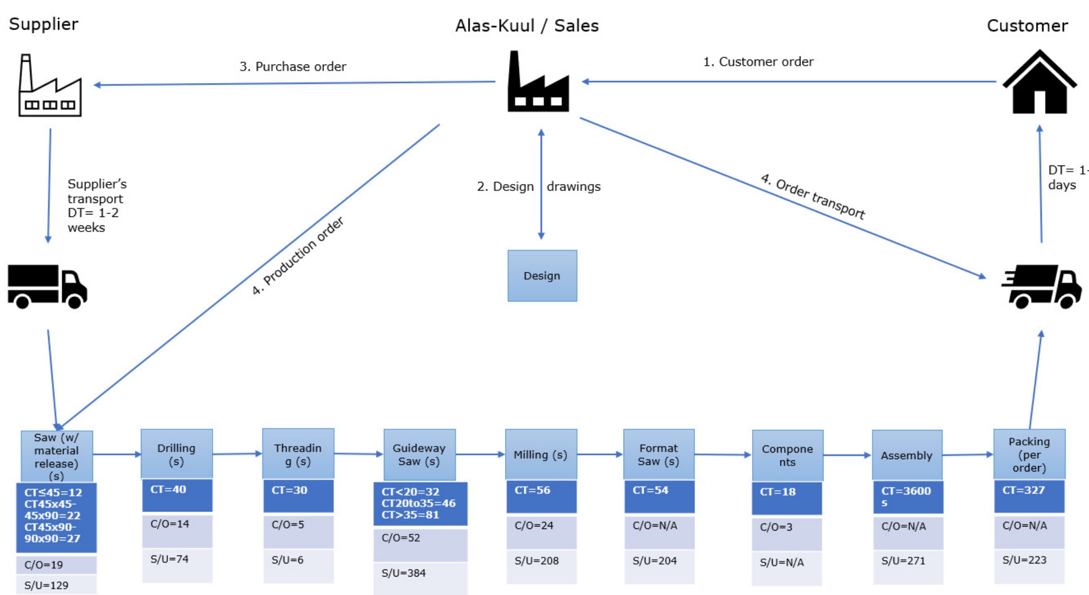


Figure 5.1 Value network map with all possible processes and times [24, 27]

Due to the processing's unconventionality, full process time is divided into three subcategories:

- C/T or Cycle time – the actual processing time, meaning the time it takes to cut the profile or guideway, drill the profile, thread it and so on;

- C/O or changeover time – the time it takes to change from one product to another for the same processing length and other characteristics. For example, the production order calls for 10pcs of 500mm long profiles, each with two holes and threads. Changeover is the time it takes to further move the profile to cut the second 500mm part or to take another 500mm part for drilling with the same characteristics;
- S/U or setup time – this is the time it takes to get the material and workplace ready before any machining or processing the material. For example, finding the profile and setting up the measuring limiter or finding and fixing the correct drilling bit before actual drilling [27].

In the value stream map, the cycle time (the actual processing) and changeover time (switching to the next product to start processing) are considered as value-added processes, as this is the actual time the production worker processes customers product. Setup time is regarded as non-value-added time and although it cannot be eliminated, efforts should be made to reduce it to minimum [27].

5.4 Product and process occurrence frequency

To get a sense of repeatability in orders, products and processes, 2020 and 2019 stock movements by sales were analysed. Articles and services combined, there was around 800-1000 unique lines for each year. The top 100 articles by quantity of pieces and sales volume accounted for 88% and 87% of all pieces sold in 2019 and 2020 respectively and for 56% and 62% of total sales revenue for 2019 and 2020 respectively, a sufficient amount of majority to give a correct overview of most articles, processes and value. Before dwelling into data, it is important to note decrease in sales between 2019 and 2020 by 32% due to pandemic [14].

In data selection, all articles are divided between components, profiles and services: components as stand-alone part sold separately or assembled together; profiles as aluminium profile material; service in terms of processing like assembly, saw cutting, drilling, threading etc. The results display (table 5.1):

- Components account for 70% of product quantity for the production workers while providing 38% of sales volume;
- The profiles account for only 7% of cut pieces for the production workers while providing as much sales volume as components;
- Service accounts for 24% of work and the similar amount of sales volume [14].

Table 5.1 2019 and 2020 quantity and sales data [14]

Type	Qty in pieces		Sales in euro	
	2019	2020	2019	2020
Components	69,5%	67,0%	37,7%	38,5%
Profiles	5,6%	7,6%	38,4%	38,7%
Service	24,9%	25,4%	23,9%	22,8%

These percentages alone do not give a specific picture yet as it has a lot of variability in terms of quantity and time. Under components most of the quantity comes from different fixing components like nuts and bolts, hence the large difference of quantity compared to profiles but very similar sales volume. As the invoicing for cutting of profiles is done separately and falls under service, the real value apart from material is under service processes and expanding this type, four main processes surface that generate the most volume in quantity and sales combined: Assembly, drilling, cutting and threading (see table 5.2). In terms of pieces, cutting, drilling and threading are top three but as assembly is calculated by hourly rate, the qty is smaller while the sales revenue it provides is higher. It is also important to point out that although profile saw cutting is divided by ≤45x45mm, 45x45-45x90 and 45x90-90x90mm profiles for the purpose of invoicing the customer as it takes a bit longer in process for larger profiles, it is all done in a single machine and such differentiation is not made in other processings [14].

Table 5.2 2019 and 2020 quantity and sales data for service type [14]

Type	**2020**		**2019**	
	Qty (pieces)	**Sales (€)**	**Qty (pieces)**	**Sales (€)**
Drilling	12 253,0	22 996,5	22 673,0	37 858,8
Saw cut ≤45x45mm	11 546,0	11 372,6	11 088,0	10 713,7
Thread M8	11 514,0	10 846,1	16 513,0	14 050,3
Transport	574,0	7 009,9	524,0	7 048,8
Guideway cutting	2 583,0	5 472,0	1 425,0	1 560,0
Saw cut 45x45-45x90mm	3 112,0	4 620,0	2 859,0	4 123,3
Mill cutting	867,0	2 370,6	5 436,5	10 022,0
Saw cut plastics	2 779,0	1 354,3	1 076,0	475,9
Saw cut angle	404,0	1 179,0	485,0	1 463,1
Saw cut 45x90-90x90mm	616,0	1 163,9	1 199,0	2 033,2
	Qty (hours)	**Sales (€)**	**Qty (hours)**	**Sales (€)**
Assembly	1 340,3	48 034,4	2 566,6	61 625,0

From this data, it is possible to construct the value stream network of a general product which consists of top orders in terms of quantity and sales combined: Saw cutting for ≤45x45mm profile, drilling and threading. Guideway cutting's quantity will be subtracted to get the number of unique routings for the three. From the top 100 order line for 2020 analysis, this covers 18,8% of quantity and 4,6% of sales revenue. The high difference between quantity and sales revenue is explainable with assembly, a process which only accounts for 2,8% in quantity but 41,3% of sales revenue [14].

5.5 Main service value network analysis

From the information from product and process occurrence frequency, a value network map was created which can be seen in figure 5.2. This is a typical order that consists of profiles cut to size, holes drilled and threaded, some components added to the order and packed all together. Although packing was not present in the table 5.2 as it is not separately invoiced currently, as a vital part of the process it is listed here. The process times are taken from measurements in appendix 4 [27].

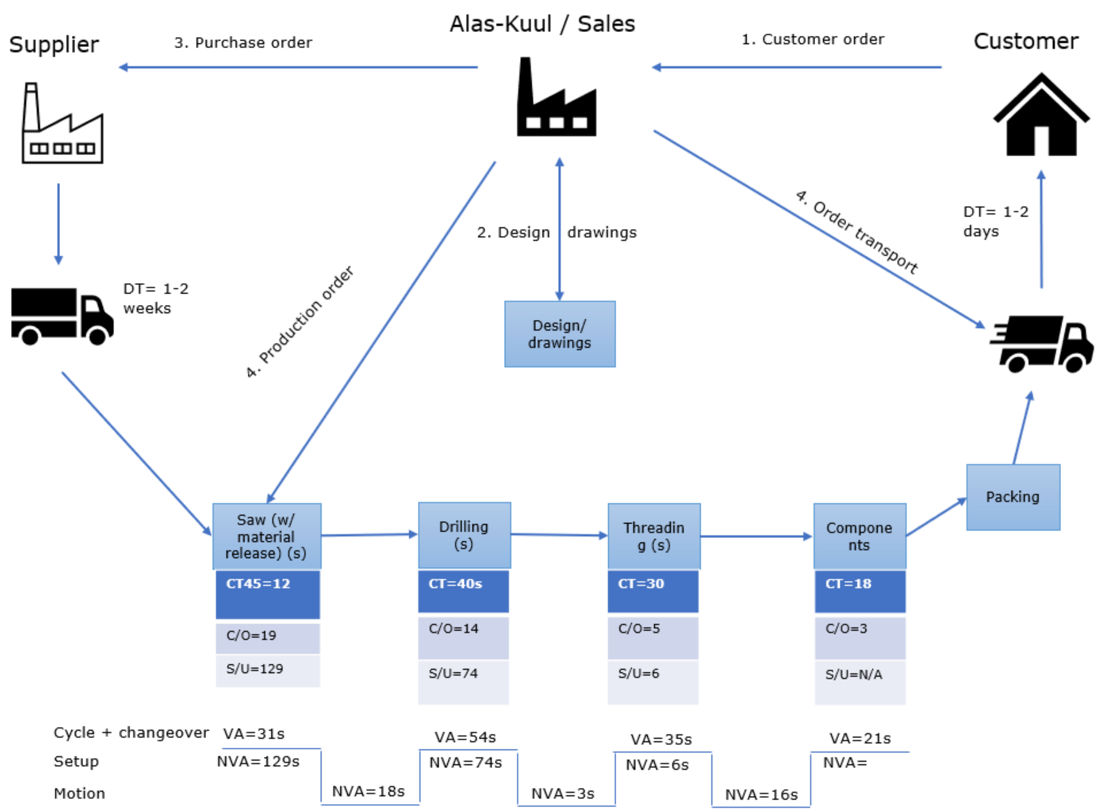


Figure 5.2 The service value network that covers 18,8% of quantity and 4,6% of sales revenue [14, 27].

Analysing the main product streams gives the possibility to measure motion as well. Motion has been physically measured on shop floor (see Shop floor under Graphics). Adding together the obtained values show 141 seconds per part that add value to the customer and 246 seconds that do not and should be further analysed for improvement.

6. PRICING MODEL ANALYSIS AND UPDATE

6.1 Value network mapping's insight into pricing

In a job shop environment, the whole process of pricing a product is different and time consuming and can be considered quite wasteful process. As the end product has low repeatability and is highly customized by customers specification, the pricing has to be calculated according to the order specification for every order (unless it is a replica of exact order in the past). There are two main components of the pricing:

1. Fixed costs, incorporating the investments to infrastructure, rent, machines etc. Fixed costs do not depend on the number of products produced.
2. Variable costs incorporate the costs that vary according to the number of products produced – direct material, direct labour etc. When production increases or decreases, variable costs respond accordingly [28].

As job shop environment has low automation and less investments into machinery, the break-even point is lower compared to continuous production thanks to less fixed costs. Variable costs on the other hand are much higher in job shop as the processes are labour-intensive in terms of human capital. The positive side of this is that when operating in low level, the break-even point is lower thanks to less investment into machinery, which makes it more flexible and resilient to economic turmoil. It is always easier and quicker to reduce working time or even lay off labour than sell machines. However, when operating in high level, the break-even point rises fast and the possibility to automate to benefit from economies of scale are low. Large proportion of the cost will be from variable costs, keeping the profit per unit relatively low [24, 27].

This indication confirms the findings from strategic analysis on why the variable costs need to be kept as low as possible to keep profit at reasonable level and be competitive in the market. That means working to remove wastes in processes is as important in job shop in terms of costs than it is in continuous production layouts. On top of that, value network mapping will also simplify the price calculation to make sure the services are appropriately priced. As variable costs make up the larger part of unit price and must be calculated for most of the orders, the value network will provide input into how much resources are really needed in each process [17, 19].

When analysing the applicability of Lean management in Alas-Kuul, several improvements were also discovered for the pricing model. One main discovery was that the processes and services were priced according to their value-added time, which creates uneven profits across services provided. Problem is that in job shop, the setup time is most often longer than actual cycle time and only pricing the cycle time means large proportion of process is not priced for the customer. Table 6.1 shows Alas-Kuul's current price list for processing with the full time for each process (setup + cycle) and reoccurring time (changeover + cycle). Result is an inconsistent pricing, which in most cases do not consider the time it takes the production worker before he can start the actual machining process [14].

Table 6.1 Process's price and time [14]

Process	**Price (€/cut)**	**Initial time (s) (Setup + cycle)**	**Price per 60 sec (€)**	**Reoccurring time (s) (changeover + cycle)**	**Price per 60 sec (€)**
Saw cut ≤45x45mm	1,00 €	140,75	0,43	30,50	1,97
Saw cut 45x45-45x90mm	1,50 €	150,50	0,60	40,25	2,24
Saw cut 45x90-90x90mm	2,00 €	155,50	0,77	45,25	2,65
Guideway <20mm*	1 €	415,50	0,14	83,50	0,72
Guideway 25-30mm*	2,50 €	429,75	0,35	97,75	1,53
Guideway 35+mm*	4,00 €	465,00	0,52	133,00	1,80
Format saw cut	4,00 €	257,50	0,93	83,5	2,23
Drilling	2,00 €	114,00	1,05	53,75	2,23
Threading	1,00 €	35,00	1,71	35,50	1,69
Milling	4,00 €	264,25	0,91	80,00	3,00
Assembly	35,00 €	3871,25	0,54	3600,00	0,58

The two lowest lower price per 60 seconds on both columns are marked with yellow, the two highest price per 60 seconds on both columns are marked with green.

*Guideways price is variable, depending on customer and sales engineer – for example for <20mm it is usually between 0,5€ to 2€; for 25-35mm it is usually between 2€ or 3€; for 35+mm it is between 3€ and 5€. In the system it is registered as one service article as opposed to different articles for profile section dimensions [14].

6.2 Pricing model update

Table 6.1 is a valuable tool to implement price changes that takes into account the setup and changeover times as well. Analysis in Erply for past orders from the end of 2017 indicated that the price list for services has been the same (no price updates). Estonian statistics is indicating that besides increasing investments of industry, the average monthly gross wages and salaries are increasing too – from 1221 euros in 2017 to 1448 euros in 2020, an 18,6% rise in four years and as the graph show consistent increase from 2009, it is reasonable to expect the increase to continue. For Alas-Kuul to stay competitive in the job market, salaries will have to grow too, and this means higher expenses on manual labour [16, 29].

Figure 6.1 Average monthly gross wages development over last 10 years [29]

To cope with rising prices, the price model should be updated with first step in increasing the prices that are currently below the average of 0,70 euro on setup + cycle time column on table 6.1.1. After careful analysis, the proposed price increase would be:

- increasing prices for saw cut 45mm by 20% to 1,20 euro and 90mm by 15% to 1,70 euro per cut;
- Increasing prices for <20mm guideway cutting by 100% to 2,00 euro, 25-35mm by 40% to 3,50 euro and >35mm by 25% to 5,00 euro per cut;
- Increasing assembly hourly charge by 10% to 38 euro per hour;

The reason for difference in price increase is due to different factors like sales volume of specific service (larger volume of profile cuttings vs guideway), the amount the setup time a service needs and the market sensitivity for cutting price (for example the price per meter for guideway is higher than aluminium profile, thus cutting service amounts to smaller part from the overall order). The revised pricing table 6.2 show updated prices per cut and re-calculated prices per 60 seconds of labour.

Table 6.2 Revised pricing table with recalculated price per 60 seconds of labour

Process	**Price (€)**	**Initial time (s) (Setup + cycle)**	**Price per 60 sec (€)**	**Reoccurring time (s) (changeover + cycle)**	**Price per 60 sec (€)**
Saw cut ≤45x45mm	1,20 €	140,75	0,51	30,50	2,36
Saw cut 45x45-45x90mm	1,70 €	150,50	0,68	40,25	2,53
Saw cut 45x90-90x90mm	2,00 €	155,50	0,77	45,25	2,65
Guideway <20mm	2,00 €	415,50	0,29	83,50	1,44
Guideway 25-30mm	3,50 €	429,75	0,49	97,75	2,15
Guideway 35+mm	5,00 €	465,00	0,65	133,00	2,26
Format saw cut	4,00 €	257,50	0,93	83,50	2,87
Drilling	2,00 €	114,00	1,05	53,75	2,23
Threading	1,00 €	35,00	1,71	35,50	1,69
Milling	4,00 €	264,25	0,91	80,00	3,00
Assembly	38,00 €	3871,25	0,59	3600,00	0,63

Proposed price increases are underlined.

6.3 Packaging cost

The second issue is packing. At the moment packing is not charged for customers but to make sure aluminium profile with smooth anodized surface reaches the customer the same way, they need to be packed fully into cardboard when using transportation company and sometimes the whole shipment on a pallet if the weight is above 20kg. While the cost of packing material is insignificant at this stage, the problem is the packing process – since 95% of orders differ from profile lengths and components set, the packing is difficult to improve or automate, so it is a manual task that takes time. According to measured cycle times packing takes around 550 seconds and with smaller orders, packing can take up significant portion of the whole order time and should be invoiced. When using the pricing logic behind Assembly operation, the cost for packing should be around 5€ by the time it takes (Appendix 4). According to table 5.2, in 2020 574 transports lines for customers were sold, out of which most cases should be invoiced to the customer.

7. LEVEL SCHEDULING

Level scheduling or Heijunka is vital for a business to allocate resources appropriately but is also something that needs very accurate input to function properly, even more so in a job shop production environment. In a normal business environment, standard processing times combined with forecasting helps to level the schedule. In a job shop environment, there is very low amount of standardized production orders with varying processing lengths and little to no forecasting, which makes scheduling a real challenge. As different processes take different amount of time in current case, the load levelling and scheduling of orders must be done according to the real demand, not on paper which is possible if one has specified routings and pre-determined economic production bathes. Nevertheless, load levelling is very important as there is a danger of mismanagement of resources in such an environment – thus constantly creating days with resource abundance or shortness. It is the authors own experience that since job shop projects are not standardized and thus measures in a time-critical way as usually production, the projects start to drag on and are not managed in the most efficient way. If time and scheduling are not measured in such an environment, there will be time-based wastes [1].

In the value network mapping, timely values were set to each individual part or process in the system. Although they vary depending on the material in the process (for example guideway cutting where the cutting positions must first be calculated), it still gives an appropriate value to how much time a process can take, especially when combining the outcome of different cycle times with percentile value. This is an input to schedule the production more evenly and have clear visual overview on the near future resource needs. For such a system to work, order lines have to have a timely value, even for searching components (10 vs 200 components is a large difference). Essentially what is being done is applying the products production time logic to processing time and calculating every customer order to have a timely value. The challenge here is the software, that needs to be able to set timely values to all order lines, then calculate them by orders and lastly to add them to a calendar system, showing the booked or available time for each day in the future.

Alas-Kuul's main software is a material planning software called Erply. As Alas-Kuul is mainly a sales and service company, the software is built for that and its support for production functions are lacking. This in turn means investment to either upgrading the current software or having a second software working side-by-side Erply. As mentioned before and as with any software, it is only as good as the input information, so the software must be convenient to use and not create too many additional steps in daily life. Currently, there are no KPIs in place for delivery reliability and the material planning software has no possibility of measuring the promised delivery date versus the actual delivered date. By different assessment by the production workers, the delayed orders by overbooked resource happens few times a week, but as this is just a guess, conclusions cannot be made from it apart from the fact that obviously deficient scheduling will affect dependability [14].

Another outcome of scheduling problem is overtime work. In 2020, 62 hours of overtime work was registered and in 2019, that number is 92 hours give and take. This is roughly in line with change in revenue decrease for 2020. But as economy is expected to recover, overtime work can be expected to recover too. In the authors opinion, at least 50% of overtime work could be abolished with proper scheduling program, giving a real monetary incentive to implement such a software.

A good example software for such needs would be Scoro Management software with its possibility to track and schedule timely resources and activities in a Kanban task board. As an added value, the software provides project management help for sales engineers together with profitability tracking, showing a clear picture both in terms of sales and production. In addition, for future reference, good tools like timesheet view and time tracker for workers for easy tracking of time spent on production orders and Project template for sales engineers and designer can be added for just additional 4.50 euro per month/person. [30, 31].

To start measuring the quality of operations, dependability and speed, delivery time is the metric that will be used to measure the delivery precision to customers first promised delivery time. The delivery time will be measured monthly, by analysing the delayed orders to all delivered order lines. Target is to arrive at 95% delivery precision and it shall be reviewed on monthly meetings. In case the delivery precision falls instead of rises, a special meeting will be held to assess the issues causing the delay.

8. 8 WASTES

The original 7 wastes are updated to include employee's unused potential and is a classical list of most common wastes that can be found in every type of production to a degree. It is important to remember that every waste has a cost and a delay, so decreasing waste has a direct effect to a company's financials. It is also important to understand that wastes create more wastes. A good explanation to that can be found on Paul Akers „2 seconds of Lean" [25]: The trigger of other wastes is overproduction, which leads to the need of transport for the overproduced goods and the need to store them, creating excess inventory. Then if a defect is found, this leads to overprocessing the overproduced parts and that in itself means wasted motion and waiting as production workers are wasting their potential repairing the defects instead of producing quality products for customers and improving processes. Below are the selected wastes analysed in the context of Alas-Kuul [25, 32].

8.1 Inventory size

Most of the problems with scheduling are rectified by keeping an inventory of most used parts, but this creates another problem – large inventory and missing or obsolete parts. Table 8.1 compares revenue and stock value in 2019 and 2020. Of course, the effect of global pandemic was evident, but it also points out the weakness a large stock creates – while revenue fell 32%, inventory decreased just 3% and keeps holding finances tied down under it [14].

Table 8.1 Inventory overview 2019 vs 2020 [14]

	31.12.2019	**31.12.2020**
Revenue	1 357 176 €	920 200 €
Stock value	131 100 €	127 200 €
Discount value	19 223 €	20 073 €
Discounted profiles	9 143 €	13 500 €
Discounted components	10 080 €	6 573 €

Second problem with large inventory is write-off's – damaged or lost material. The larger the inventory, the more material is lost or damaged while plenty of buffer means work can continue as usual and no immediate actions is needed to take or root of the problem rectified. This comfort costs a lot in the end, as can be seen on table 8.1 and further illustrated on figure 8.1 [14].

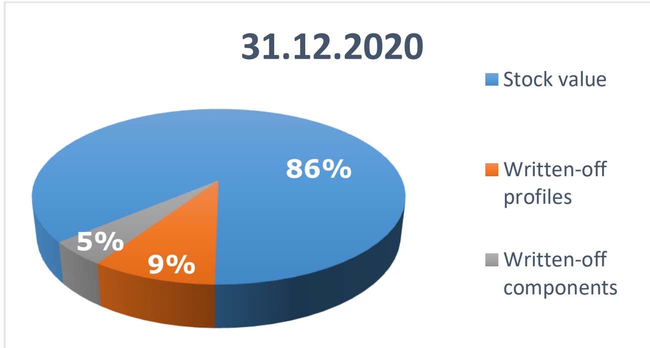


Figure 8.1 Pie-chart showing the amount of written-off profiles and components annually [14]

But that is just the material, wasted time is not being counted since the parts have been ordered and stocked and, in many instances, installed but not invoiced. This is most likely also the result of having abundance of inventory – when there is no shortage of parts and they are not per order, there are no visual cues to help discover human errors.

When reducing inventory, one must keep in mind flexibility – as pull system is used, inventory gives a possibility to be more flexible in sequencing the work and to respond to customer orders quickly. As the supplier is from Germany, cost-effective delivery time is around 2 weeks, which means to lose inventory would mean minimum order time of 2 weeks + processing. This would take away one of Alas-Kuul's strengths, which is response speed to market demands [1, 14].

Analysing the stock with 24 months of usage/demand, often the stock never even reaches the suggested reorder point. Although the system has minimum order quantity and reorder points set in, they are not reviewed periodically, which means they cannot be trusted and to make sure deficiency does not happen, material and components are ordered in abundance. Figures 8.2 and 8.3 show an example from Erply for a profile and a component – green area is the normal buffer level, yellow is 2/3 of normal and red is 1/3 of normal. In the case of a profile, too large amount has been ordered in and now it is waiting to be consumed, falling from 41 meters to 26 meters in two years, but still a lot higher than suggested buffer stock of 9 meters according to historic analysis. The case of component visualizes how inventories rise – there is a spike in demand and after that the level remains higher for months before starting to decrease again [14].

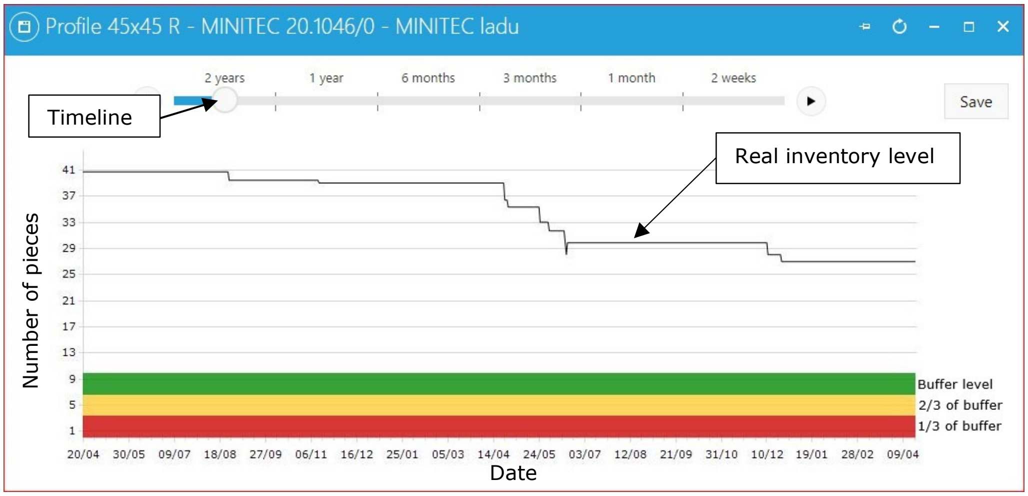


Figure 8.2 24-month inventory history for 45x45 R profile [14]

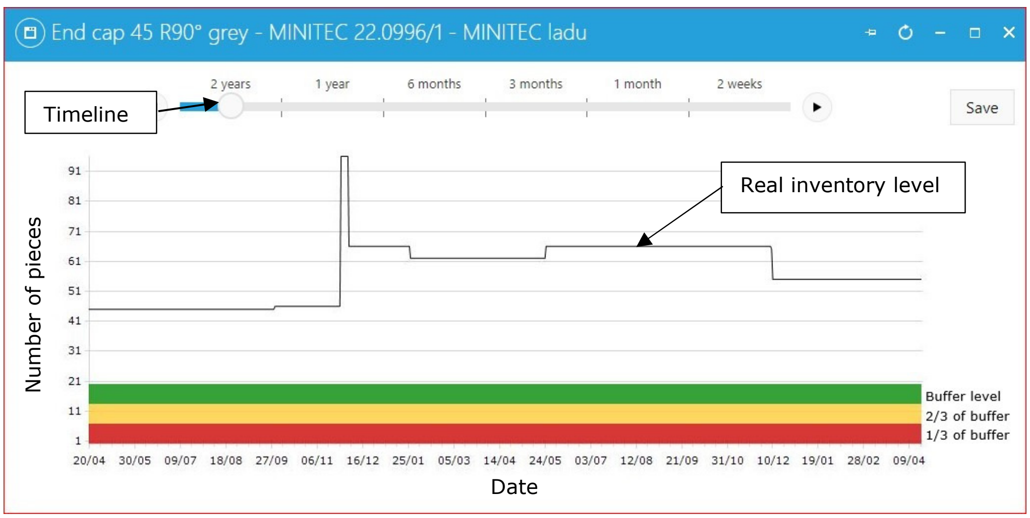


Figure 8.3 24-month inventory history for 45 R90 component [14]

Besides discounted stock this creates two additional problems – holding large amount of buffer stock is a liability in case of accidents and in case of something becoming obsolete. This can mean huge write-offs for the company if any of those scenarios come into life. And finally – it is a waste of area/room on shop floor.

Looking at the whole inventory by supplier Minitec, the average inventory turn ratio calculated from every individual item in stock is 3.4 per year in a situation, where average lead time from supplier is 2 weeks. As one of the performance indicators is speed, Kanban system can pose limitations to it, especially since the supplier is in Germany and 6-meter aluminium bars need to be transported by land. The stock reduction would consist of three levels named A, B and C with A being the high-runner articles and C being the lowest used articles:

A. Articles with inventory turn ratio higher than 7 will have a buffer stock equal to 4-month average demand from last 15 months. This will affect 55 articles with sum value of 49 700 euros as of April 30th, amounting to 35 400 after the initial reduction.
B. Articles with inventory turn ratio of 3 to 7 will have a buffer stock level of 2 months in stock by last 15 months average demand. This will affect 100 articles with sum value of 31 400 euros as of April 30th, amounting to 12 600 euros after the initial reduction.
C. All the articles with inventory turn ratio less than 3 will not be held in stock and will be order-only after current inventory is consumed. This will affect articles out of 611 with sum value of 65 500 euros as of April 30th. Out of that there is 265 articles with 0 to 1 inventory turn rate by value of 29200 euros, which will be difficult to sell at all. Remaining 36 300 worth of stock should be sold by one year according to inventory turn rates so far (1-4 annual) after which these articles will be ordered according to Kanban technique (see table 8.2 for overview) [14].

Table 8.2 Inventory volume difference before and projected [14]

	Segment A	Segment B	Segment C	Sum
Stock value (30.04.2021)	49 700 €	31 400 €	65 500 €	146 600 €
Value after new policy	35 400 €	12 600 €	29 200 €	77 200 €
Difference	-14 300 €	-18 800 €	-36 300 €	-69 400 €

Inventory reduction will be implemented and controlled by sales assistant does the purchasing, with goal of achieving 80% of the goals listed in table 8.2 within 12 months. The changes in write-offs will be monitored together with main stock volume, but no goal will be set yet as the number of different drivers for written-off stock size must be determined (Human error, average profile waste percentage, obsolete products).

8.2 Unused potential

Unused potential or employee knowledge is the latest addition to what originally was the 7 wastes. In its essence it goes together with Kaizen – continuous improvement by all parts of the system. When talking about a specific process and the employees conducting it, as they have the longest experience in this specific process, thus they are in a good position to look for improvements. This is something that comes down to companies’ culture and how motivated are its employees. According to Paul Akers, one of the most important things he learned in Lexus production plant in Japan was that Lean was not foremost for the process but for the people – motivated and developed people will happily accept changes that come with Lean, it will not frustrate them as usually with changes. For a successful implementation of Lean, it is vital that all people of an organization really accept and works with it, not just being something, that managers endorse and workers must do. In his own organisation, Paul Akers [25] has mastered this part and by now, the workers are the most proficient Lean users who come up with small improvements. According to him, the most important thing is to teach people to see wastes, that is the first pillar and basis for success. As Paul also said, outside visits are very important as it creates a sense of pride in the workers when people outside come to see their work, it makes them take it more seriously and want to be better. In the sales team, it was also decided to start inviting customers to visit the production if possible and in case of factory acceptance tests on standalone machine which are not integrated on an existing production line, the acceptance test will be hosted on the shop floor with the technicians themselves describing what and how they did and how the machine works (instead of sales engineers) [1, 25].

8.3 Wasted motion

The production floor layout is divided into three main rooms:

1. The largest room (15.6x23.2 meters) has material shelves in the opposite sides of the room, three of them for aluminium profiles and one for guideways plus the appropriate saw's for profile and guideway cutting. At one wall this room has the largest lifting door and is the main opening for incoming and outgoing materials. On the opposite wall is the lifting door that connects to the next room.
2. The second/middle room (9,1x23,2 meters) consists mainly of processing machines – format saw for polycarbonate and plywood; milling machine; grinding machine; turning machine; drilling / threading machine. Against one of the walls is also a table for hand tools and a smaller table with different electrical tools (hand drills, oils etc).
3. The third room (10,3 x 23,2 meters) has three adjacent shelves for Minitec components and one shelf for other incoming miscellaneous components and parts (SEW motors etc). This room also has washing and changing part and a corridor with stairs to the second floor, so the floor area is smaller [see Shop floor in Graphics].

The layout and allocation of machines and material positions are originally planned as to have a flow from one room to another – one room only for cutting, one for machining and then final room for components and assembly. Applying Mr. Irani's [22] suggested cell production layout and gathering the most utilized machines and parts together, the three most used processing workplaces – profile saw, drilling and threading – should all be in one room, creating a production cell. To make room for drilling, threading and component shelves in the first room, the guideway saw and guideway shelves will be moved to the first room (to be more separated from processes of second room and to allow for loading from the smaller door if needed) and one of the profile shelves would be moved to the second floor, consisting of the least used profiles. All packed and ready to ship orders would be placed next to the component stock in a specially designated area waiting for transport (see Shop floor revised in Graphics). This rearranged shop floor would mean decreased wasted motion for production workers and generally increased speed in order handling (figure 8.4) in 18,8% of the times [24].

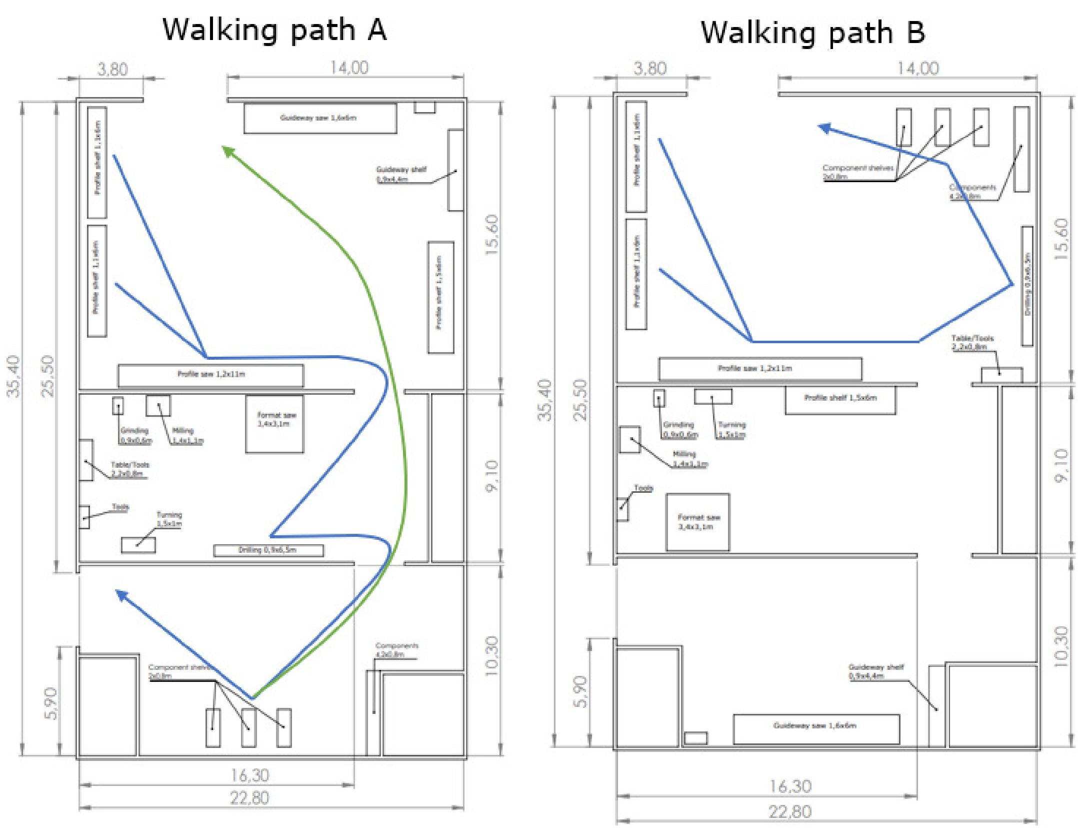


Figure 8.4 Walking path in current versus simulated floor layout for the main value stream: Walking path A – current layout, Walking path B – simulated layout.

This would reduce the amount of distance from 45-85 meters to 30-50 meters or about 40% (difference comes from if the shipment will be picked up by the customer in room three or transportation company in room one). When measuring the motion in time, it currently takes around 58 seconds just walking from one machine to the other. With rearranged layout, the motion would be reduced to 25 seconds (simulated on the shop floor). The product and process occurrence frequency showed this would be 18,8% of times. Considering service quantity data for 2020, possible reduced waste in motion can be calculated by:

$$M_W = S_{VN} \times M_R \quad (8.3.2)$$

Where

W_M is the motion waste;

S_{VN} is the number of specific services in value network;

M_R is the reduced motion:

$$M_W = 8900 \times 25 = 222500 = 61{,}8\ hours \quad (8.3.2)$$

In here we arrive at a problem – it is not possible to calculate the effect the new layout would have on the remaining 81,2% of the service quantities. It is reasonable to presume that in some cases, the new layout would introduce more motion. This demonstrates the problem with job shop – as the routings are different depending on the need, in some cases it is very difficult to exactly calculate the effect one of other change would have, especially in a smaller job shops where there is one of every type of machine.

The excessive motion in the workplace is further investigated and analysed under the 5S chapter.

9. 5 PRINCIPLES OF WORKPLACE

The 5 principles of workplace (known as the 5S) is a well-developed and often most marketed tool in Lean management with the focus on developing a workplace with order and cleanliness. While order and cleanliness are also visually pleasant, its importance lies in the wastes that will be revealed when implementing 5S. 5S is also proven to increase quality, productivity and safety. The 5S refers to five tools, which are:

1. Sort – sort through items and separate on what is needed and dispose of what is not. Unnecessary equipment and material increase waste time and motion when worker must look for a specific item through a pile of other things.
2. Straighten (order) – tidy up the workplace and place everything to its designated place or area where it can be easily found, using grids, labels, boxes etc.
3. Shine (clean and maintain) – Inspect if everything is clean and as it should be and evaluate the cleanliness and efficiency.
4. Standardize – create rules and KPI's to keep the developed changes to become a part of standard daily work routine.
5. Sustain (self-discipline) – keep the system organized. This is the hardest part of 5S, to maintain the new system for a longer period. According to Andrea Chiarini [32], leaders of successful organisations have admitted to having problems of keeping with the new discipline and after maintaining 5S over several months, practices still start to revert to the former situation [32].

In his book, Mr. Jeffrey K. Liker [1] talks about how in mostly mass productions problems accumulate over the years due to no 5S system or workplace standardisation. At one point it is true, as there is not much work-in-process is job shop, but as in job shop workplaces usually cater to larger variety of processing, there are more tools, material and fixtures present in job shop, which means it is harder to sort out only the tools and fixtures needed in a specific workplace. As 5S helps to uncover wastes in time and material, in the authors opinion it is especially important in job shop environment where machine utilisation etc. is not measured, thus allowing the wastes to go unnoticed [1].

9.1 Shop floor analysis

The shop floor at Alas-Kuul confirms the problems: large amount of leftover material waiting for the suitable customer order to use maximum amount of material. In time it tends to accumulate and form large piles of material the production worker has to search through (see figure 9.1 and 9.2) as also indicated in Chapter 3.6, Shop floor inspection.

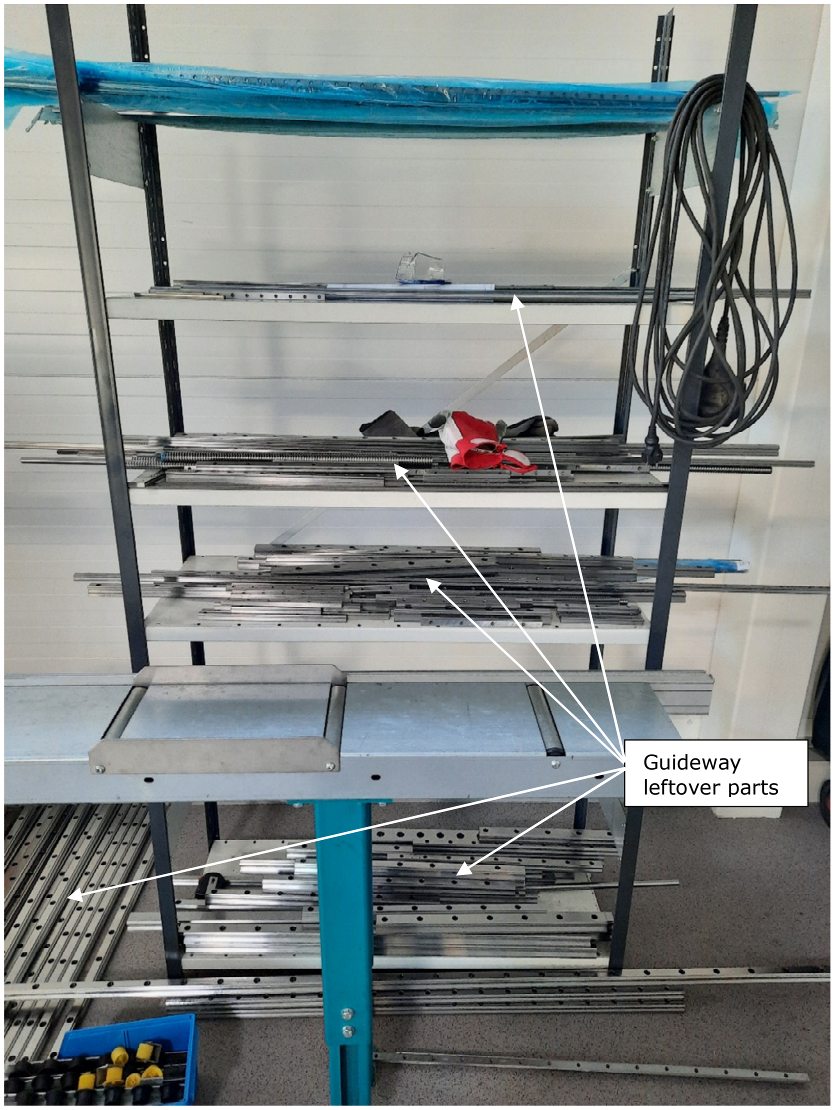


Figure 9.1 Guideway saw’s leftover material shelf waiting for suitable need

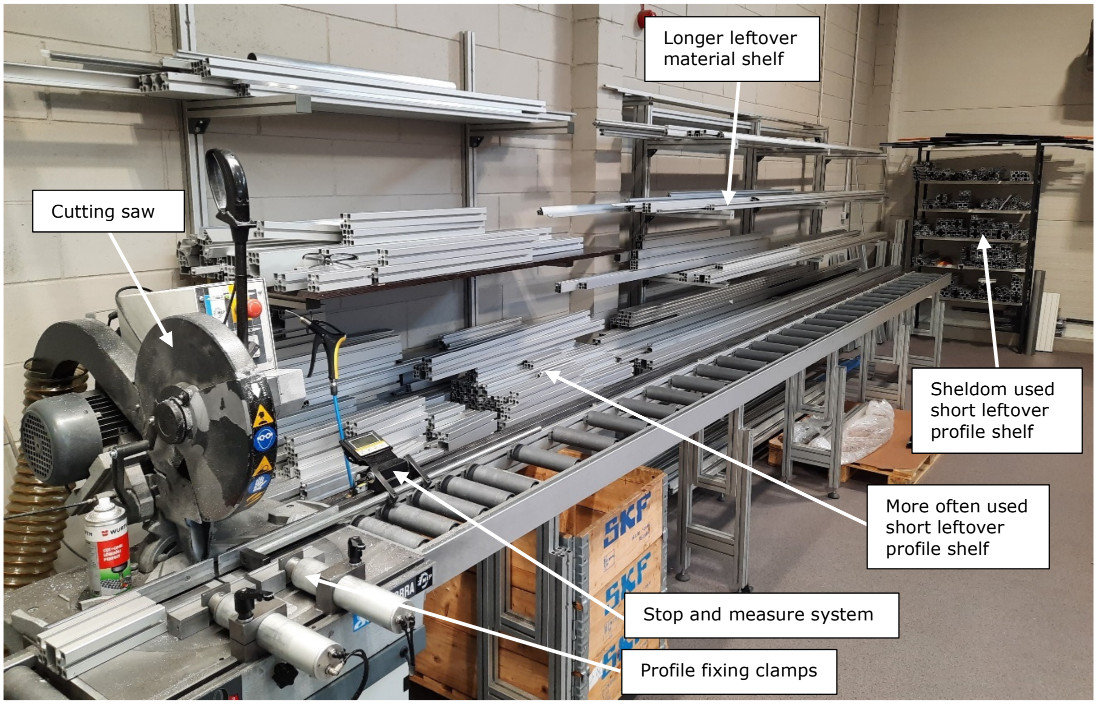


Figure 9.2 Profile saw's leftover material shelf waiting for suitable need

While it is unavoidable to have a stock of leftover material in any size waiting for appropriate order, it is a waste of motion that translates into time (setup time in this case): before taking a new 6-meter bar of aluminium or a 4-meter guideway, production worker has to ensure there isn't an appropriate bar in length and cross-section already in the leftover material. Currently there only system for leftover material is that smaller more used pieces are on the first shelf next to the saw and the longer ones (1.5 to 5 meters) in the second shelf next to the saw (see figure 9.2). The third shelf should have smaller lesser used profiles on it, but as there is no clear separation or labelling system, half of the profiles are the same as in the first shelf. Every time a new order comes in, production worker has to check the shelves and as there is no clear separation system, in some cases he might have to check all three shelves before taking a new 6-meter profile, which is why the average setup time to a simple saw with measuring tool is 129 seconds [32].

When asked if a systemised shelf would make things quicker, the production workers agreed but pointed out that they had tried to hold a system in the past, but after few weeks the disorder was back so they have given up on it. This is very common process to happen with Lean management and it will be explained further under Implementation and control chapter.

9.2 5S effect on setup time

To simulate the effect a sorted profile stock would have on the setup times of the most utilized working place in the shop floor, a system was created to sort and divide the guideways to specific places and label the shelves, so that production worker would know where to look right away and to discipline when placing a leftover profile to the shelf. The idea to test the system first on guideway leftover shelf is because profile saw is the most utilized and important machine in the shop floor. The system was not finalized right away to give production workers few weeks to try out the shelf to see if they would change anything further (figure 9.3), but 10 measurements of cycle time with setup was taken to see the different from changes (see table 9.1).

Table 9.1 Guideway saw setup times before and after 5S.

	Guideway saw	
	S/U	**S/U with 5S**
	410	207
	349	274
	140	245
	391	110
	250	154
	332	221
	152	212
	421	239
	363	138
	281	242
Median	340,5	216,5
75th Percentile	**384**	**241,25**

The effect on setup times was twofold – average setup time decreased from 384 seconds to 241 seconds, around 27% as production worker would be able to determine quickly if there was any leftover material to suit the customers' needs or would he need to take a new 4-meter bar and the second effect was the reduction of peak times, which were not so high from 75th percentile anymore (table 9.1). In addition, other tools and spare parts like cutting disks for the saw were relocated by their usage frequency.

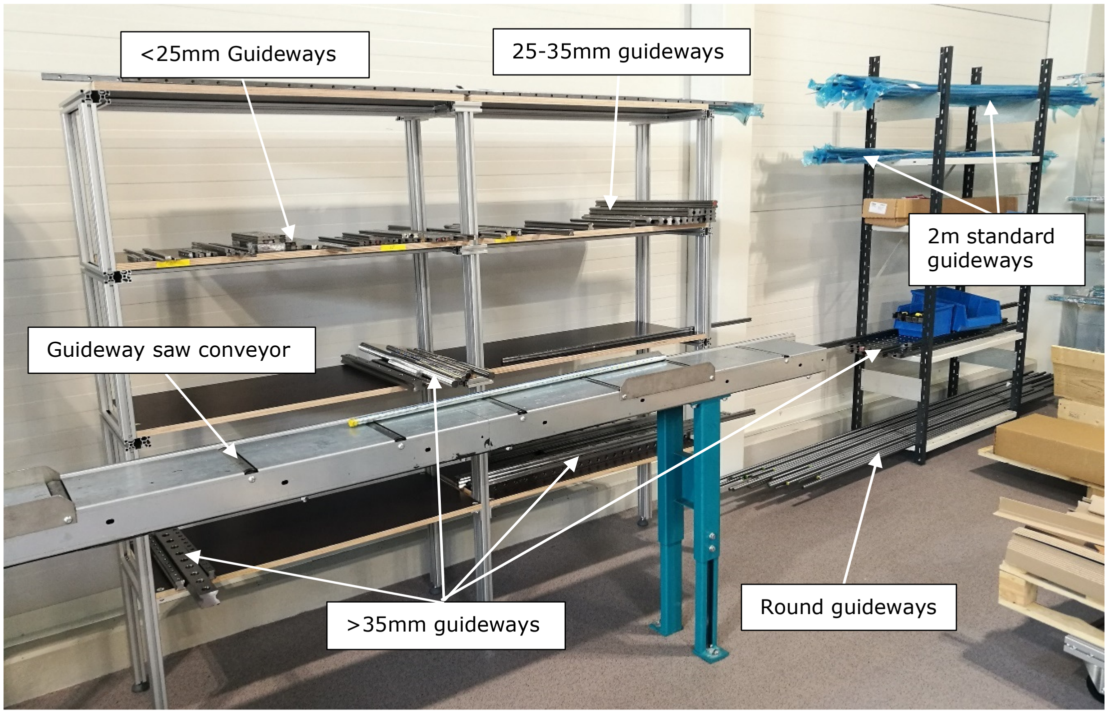


Figure 9.3 Guideway shelf with 5S in progress

Even larger effect can be expected from aluminium profile leftover shelves, as there are more leftover material and process frequency in aluminium saw cutting is several times higher than in guideway saw.

10. IMPLEMENTATION AND CONTROL

10.1 Employee engagement

For the successful implementation of any large-scale change, employee engagement is key. According to a 2001 research into engagement and burnout by Mr. W. Schaufeli et al [33], worker engagement is characterized by: "…, engagement is defined as a positive, fulfilling, work-related state of mind that is characterized by vigor, dedication, and absorption. Rather than a momentary and specific state, engagement refers to a more persistent and pervasive affective-cognitive state that is not focused on any particular object, event, individual, or behavior." It is further explained that vigor is characterized by high levels of energy, mental resilience and willingness to invest into ones' work. Dedication is characterized by a sense of significance, challenge and enthusiasm. Absorption is characterized by being deeply absorbed into one's work with focus and effortless concentration. It is important to note that burnout is, to a certain extent, on the other end of the spectrum, where worker is exhausted, cynical and lacks professional efficacy [33].

According to Gallup analytics' research poll of over 155 countries, only 15% of employees feel engaged (countries with highest engaged employees are USA, Canada and Latin-America with around 30% while the percentage of engaged employees for Western Europe is only around 10%), around two thirds are not engaged and 18% are actively disengaged. The most engaged (28% engaged) people are working in manager/executive/official positions while the least engaged (12% engaged) work in construction/manufacturing/production. This coincides with Jeffrey K. Likers [1] thoughts on why so many Lean transformation fail – the executives take up the initiative but fail to inspire and attract the production workers. Employees not engaged feel unattached to their work, they are putting time but not energy or passion into their efforts. Disengaged employees on the other hand are resentful and acting out in their happiness. Consider trying to implement Lean management to an environment of employees who are not engaged and some even actively disengaged. The probability of failure is very high. This is a very stark reminder on the general foundation in employee engagement for implementing changes. In the authors opinion, the employees at Alas-Kuul are engaged to not engaged, meaning the situation is not bad for implementing change in working culture but it must be thought through and approached strategically [1, 34].

10.2 Implementation plan

Due to general resistance against change, it is critical for changes to be implemented with strategic and continuous focus. It is the experience of author and several sources [1, 25] that most often Lean's introduction to a company is a selection of tools and changes that must be done and after the momentum dies down, everyone forgets about it and very often even the small changes will dissolve, leaving only a period of decreased motivation for workers, who feel they now have another job description point they need to do. To really benefit from Lean management, people must be trained to see wastes and problems themselves, not just to give them orders to fix this and that. After all, they are the ones who do the activities daily which makes them first person to notice problems and first person to benefit from solution. The implementation of Lean must be done with continuous systematic approach with strong support from all stakeholders (management and key personnel) by starting with small incremental steps to build trust to form a true Lean environment [1, 25].

The selected lean tools to implement in sequence are:

1. Inventory decrease policy (new buffer levels) – first to implement to limit the amount of inventory right away as it takes time to decrease – week 1 - 2;
2. Updated price model with increased prices – Implementation will not be time-consuming and it makes sense to do the changes before new scheduling software – week 3;
3. Scheduling software – third to implement as it is important to sort out scheduling problems before we introduce lean, as we need to leave some time for production workers to get used to it – weeks 5-8;
4. Lean & 5S training for production worker(s) to maximise shop floor employee potential, who will share the new knowledge and train Sales – weeks 9-11;

In addition, there will be monthly meetings where KPI's will be looked over to reflect on the changes and measure the improvement. The implantation sequence can be further seen in figure 10.1.

Task	Start week	End week	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Inventory reduction policy	1	2														
Price model update	3	4														
Monthly review meeting	4	4														
Scheduling software	5	8														
Monthly review meeting	8	8														
Lean training / sharing	9	11														
Review meeting / kaizen	12	12														
Kaizen implementation	13	14														

Figure 10.1 Lean tools implementation sequence

10.3 Evaluation and control

It is critical to monitor the changes with appropriate KPI’s to see if the performance results correspond to expected results or targets. To make sure the changes are really implemented correctly, the monitoring should go on and continue to be a part of performance metrics, not to be disregarded at the first sign of success as things tend to turn back into their former state when momentum dies down.

An appropriate key person (production workers for shop floor changes like wastes and sales engineers for scheduling) will be selected for each specific change implementation to act as change agent, who will oversee it and report results on KPIs on monthly meetings. For different KPI’s different employees will be selected, who will monitor and report the results. There are two main reasons for it – in the case with Alas-Kuul, there is no specific production manager whose job it would be and including the employees at every level to evaluate and control improvements related to their own workplace will further motivate and engage them to continue improvement, not just report numbers to someone else. For the specifics of each KPI a KPI table is created, which will feature the KPI’s along with targets, goals, responsible people and so on (see table 10.1) [34].

Table 10.1 Specific information on each KPI for better overview

KPI table	
KPI name	**Reduced Write-Offs**
How Calculated	Percentage of inventory
Target value	-40% for first year, -10% for 2nd and 3rd
Monitored by	Sales Assistant
Monitoring frequency	Annual
Take action if	Decrease less than -35% first year, -5% second and third year
Required Action	Quarterly stock inspections, root cause analysis
KPI name	**Delivery precision**
How Calculated	percentage of delayed orders
Target value	95% delivery precision
Monitored by	Sales engineers
Monitoring frequency	Monthly
Take action if	below 93%
Required Action	Meeting to review problems
KPI name	**Setup times**
How Calculated	75th percentile from 10 measurements
Target value	3…10% decrease from last value
Monitored by	Worker
Monitoring frequency	Quarterly
Take action if	Time not decreased
Required Action	Shop floor brainstorming
KPI name	**Pricing model**
How Calculated	Compare to statistics of general economy and salary increase
Target value	To grow in conjunction with general price increase
Monitored by	Sales Engineers
Monitoring frequency	Annual
Take action if	Customers unhappy
Required Action	Positive arguments (faster delivery, longer payment terms, conditional discounts)
KPI name	**Overtime work**
How Calculated	Number of hours
Target value	3…10% decrease from last value
Monitored by	Worker
Monitoring frequency	Quarterly
Take action if	Time not decreased
Required Action	Shop floor brainstorming

RACI (R for Responsible, A for accountable, C for consulted and I for informed) matrix is a responsibility assignment and overview table that will show exactly who is responsible for which change implementation and KPI along with who will consult and who should be informed (see table 10.2) [35].

Table 10.2 RACI matrix [35]

Change / KPI	Production worker 1	Production worker 2	Production worker 3	Sales assistant	Sales Engineer 1	Sales Engineer 2	Designer	CEO
Price model update	I	I	I	I	R/A	R/A	C	C
Scheduling program	I	I	I	I	A	A	I	R
Lean training	A	A	A	I	I	I	I	R
Inventory decrease	I	I	I	R/A	C	C		C
Inventory volume KPI	I	I	I	R	A	A		I
Delivery precision KPI	R	R	R	I	A	A		I
Setup times KPI	R/A	R/A	R/A	I	I	I	I	I
Price model KPI	I	I	I	I	R/A	R/A	I	I

11. COST OF IMPLEMENTATION AND PAYBACK

Before carrying on with investment and benefit calculations, average employees' hourly cost C_E for the employer is needed, which can be calculated by:

$$C_E = (S_E \times T_S) \div H_M \qquad (11.1)$$

Where:

C_E is employee's average hourly cost for Alas-Kuul [36];

S_E is employee's average salary;

T_S is Social Security Tax [37];

H_m is hours in a month.

$$C_E = (2205 \times 1{,}338) \div 160 = 18{,}44€/h$$

11.1 Scheduling software

The cost for Scoro planning and management software will have an initial training and implementation fee of 799 euros, after which there is a monthly fee according to users and package. In this proposed case, it would be the basic package for 6 users for the basic package. Quarterly cost C_s after initial investment can be found by [31]:

$$C_S = M \times E \times C_{SB} \qquad (11.1.1)$$

Where:

C_S is the running cost of software for the company;

M is the number of months;

E is the number of employees;

C_{SB} is the base cost of software per month.

$$C_s = 3 \times 6 \times 19 = 342{,}00€$$

Apart from improvement in delivery precision, it is possible to calculate potential saving from reducing overtime hours C_{OT} by 50%:

$$C_{OT} = \frac{OT_A}{M} \times C_E \qquad (11.1.2)$$

Where:

C_{OT} is the cost of overtime for employer in hours;

C_E is employee's average hourly cost for Alas-Kuul [36];

M is the number of months (4 for quarter)

OT_A is the average overtime, which can be calculated by:

$$OT_A = \frac{OT_{2019} + OT_{2020}}{2} \qquad (11.1.3)$$

$$OT_A = \frac{92 + 62}{2} = 77h$$

$$C_{OT} = \frac{77}{4} \times 18{,}44 = 354{,}97€$$

Apart from the initial cost, the quarterly cost of scheduling software Scoro is lower, meaning financially it is projected to keep the running costs paid back by the reduced overtime work. When adding the benefit of reduced problems of scheduling that effect motivation of workers plus increased customer satisfaction though better on time delivery precision, this investment's benefits outweigh the initial cost of implementation.

Unquantifiable benefits:

- Clear visual overview of workload for longer timeframe;
- Possibility for management to see remotely of the workload and resource use;
- Increased motivation as workload is more evenly levelled and smoother, less surprises.

11.2 Reduced setup by 5S implementation

Pilot test in Guideway saw cutting showed that the setup time for new order can be reduced by 27%. Simulating the same 5S system with profile saw showed even larger reduction – around 35%, mostly since in guideway cutting there is still hole offset which must be calculated which is not present in profile saw. Erply presented the following data on how many unique service lines were for guideway and profile saw:

- 189 unique lines for guideway cutting;
- 490 unique lines for 45mm profile saw cutting;
- 208 unique lines for 45-90mm profile saw cutting;
- 98 unique lines for 90-180mm profile saw cutting;
- 28 unique lines for 180-270mm profile saw cutting [14];

The sum of reduced setup time for Hiwin guideway cutting service according to 2020 volumes can be calculated by:

$$SU_{IH} = (SU_O - SU_N) \times N \tag{11.2.1}$$

Where:

SU_{IH} is the improved setup time;

SU_O is the old setup time (before 5S);

SU_N is the new setup time (after 5S);

N is the number of setups.

$$SU_{IH} = (384 - 241) \times 189 = 27027s = 7{,}5\ hours$$

The sum of reduced setup time for profile saw cutting service according to 2020 volumes SU_{IP} can be calculated by the same formula as Hiwin guideway, only N is a sum of different profile saw cuts as profile service is divided into articles by section measures:

$$N = N_1 + N_2 + N_3 + N_4 \quad (11.2.2)$$

$$N = 490 + 208 + 98 + 28 = 824s$$

$$SU_{IP} = (129 - 84) \times 824 = 37080s = 10{,}3\ hours$$

The sum of both cutting service's quarterly decreased times values SU_{IQ} can be found by the formula:

$$SU_{IQ} = \frac{(SU_{IH} + SU_{IP})}{M} \quad (11.2.3)$$

$$SU_{IQ} = \frac{(27027 + 37080)}{4} = 16027s = 4{,}5h$$

The monetary hourly value can be found by formula:

$$SU_{CE} = (\frac{SU_{IQ}}{SH}) \times C_E \quad (11.2.4)$$

Where:

SU_{CE} is the setups quarterly times in hour cost to employer;

SU_{IQ} is the sum of guideway and profile cutting service quarterly times;

SH is value that needs to be divided with to change from seconds to hours.

$$SU_{CE} = \left(\frac{16027}{3600}\right) \times 18{,}44 = 82{,}10€$$

Unquantifiable benefits:

- Improved overview of the workplace and tools, easier to notice if something needs replacing or maintenance.

11.3 Inventory write-off reduction

There are several benefits for lower inventory volume and moving towards Kanban system, including reduced risk of obsolete or damaged parts and less of company's financials tied under the stock. One of the benefits is less write-offs in terms of lost or damaged parts, which will be calculated. The calculation will look at the situation in one year after implementing inventory reduction policy.

First, it is important to calculate the reduced inventories one year after new policy per A, B and C segment:

$$I_{SA} = I_{AC} - I_{AR} \quad (11.3.1)$$

$$I_{SB} = I_{BC} - I_{BR} \quad (11.3.2)$$

$$I_{SC} = I_{CC} - I_{CR} \quad (11.3.3)$$

Where:

I_{SA}, I_{SB} and I_{SC} are reduced inventory values after new policy (€);

I_{AC}, I_{BC} and I_{CC} are current inventory values for segment A, B and C (€);

I_{AR}, I_{BR} and I_{CR} are projected inventory values for segment A, B and C one year after the new policy implementation (€):

$I_{SA} = 49700 - 35400 = 14300€$

$I_{SB} = 31400 - 12600 = 18800€$

$I_{SC} = 65500 - 29200 = 36300€$

After finding the individual values of reduced volume for each segment, it is possible to calculate the projected total reduced inventory:

$$I_{TI} = I_C - I_{SA} - I_{SB} - I_{SC} \tag{11.3.4}$$

Where:

I_{TI} is the total improved inventory value in (€)

I_C is the current total inventory value in 15.04.2021 (€)

$I_{TI} = 146600 - 14300 - 18800 - 36300 = 77200€$

From the total improved inventory value, it is possible to calculate the percentage of reduced inventory and apply it to write-off value to get a projected reduction in write-offs too:

$$I_{TIP} = \frac{I_{TI} \times 100}{I_C} \tag{11.3.5}$$

$$I_{TIP} = \frac{72200 \times 100}{146600} = 49\%$$

To find the projected reduction in annual write-off's, the reduced inventory percentage will be calculated from the annual write-off's sum value, where first the sum value of write-offs for 2020 will be calculated by formula:

$$I_{SWO} = (I_{PWO} \times 0{,}97) + I_{CWO} \tag{11.3.6}$$

Where:

I_{SWO} is the sum of inventory write-offs for 2020;

I_{PWO} is the profile write-off value in 2020 (minus 3% for normal leftover which cannot be solved);

I_{CWO} is the component write-off value in 2020;

$I_{SWO} = (13500 \times 0{,}97) + 6573 = 19668€$

To find the projected reduced write-off's, use formula:

$$I_{RWO} = I_{SWO} \times 49\% \tag{11.3.7}$$

Where:

I_{RWO} is projected reduced write-off's value by the new inventory reduction policy:

$I_{RWO} = 19668 \times 49\% = 9637{,}32€$

Unquantifiable benefits:

- Reduced risk for obsolete stock;
- Reduced risk for damaged goods;
- Increased shop floor room optimisation;
- Less time wasted on inventory checks, problems become visual.

11.4 Updated pricing model

The main points for pricing model were the increase in prices for profile saw cut for up to 45mm and 45-90mm and assembly hourly cost. Due to lack of input data on different guideway measures sold, the difference between current and proposed pricing model cannot be calculated.

The basis for calculation will be Table 5.2 2019 and 2020 quantity and sales data for service type [14]. As the continuity of pandemic is not yet clear, the basis of calculation will be the lower 2020 data as to rather underestimate than overestimate potential gains. The additional revenue per quarter from updated prices can be calculated by formula:

$$SR_I = \frac{(SP_N - SP_C) \times S_N}{4} \qquad (11.4.1)$$

Where:

SR_I is the improved Service Revenue (€);

SP_N is the new Service Price (€);

SP_C is the current service price (€);

S_N is the number of services provided in 2020;

For profile saw cut 45mm:

$$SR_I = \frac{(1{,}20 - 1{,}00) \times 11546}{4} = 577{,}30€$$

For profile saw cut 90mm:

$$SR_I = \frac{(1{,}70 - 1{,}50) \times 3112}{4} = 155{,}60€$$

For assembly hourly charge:

$$SR_I = \frac{(38 - 35) \times 1340}{4} = 1005{,}00€$$

Additional revenue per quarter from packaging can be calculated by the formula:

$$PR_I = \frac{(PR_P \times TR_C) \times 0{,}75}{4} \qquad (11.4.2)$$

Where:

PR_I is the improved packaging revenue (€);

PR_P is the proposed packaging cost (€);

TR_C is the current transport cost (€);

$$PR_I = \frac{(5 \times 574) \times 0{,}75}{4} = 538{,}13€$$

For the sum of added revenue from pricing model, the quarterly price increases need to be summed up:

$$PM_I = SR_I^1 + SR_I^2 + SR_I^3 + PR_I$$

Where PM_I is the improved pricing models added revenue (€).

$$PM_I = 577{,}30 + 155{,}60 + 1005{,}00 + 538{,}13 = 2276{,}03€$$

Unquantifiable benefits:

- Easier to sell small incremental price increases than single large one;
- Increased profitability.

11.5 Payback period table

The costs associated with implementing the lean management with the potential calculated savings and benefits can be found in the tables 11.1 and 11.2. The costs are divided into five columns – the initial cost of implementation and the quarterly cost. The cost for three production workers for Lean management is also included in the table [38].

Table 11.1 Costs of implementation [31, 38]

Cost type	**Initial**	**1st quarter**	**2nd quarter**	**3rd quarter**	**4th quarter**
Scoro scheduling software	799 €	342 €	342 €	342 €	342 €
Lean management training (3 people)	870 €				
Inventory analysis to set new buffers (8h per month x CE)	590 €				590 €
Initial Lean/5S implementation on shop floor (16h per month x CE)	560 €				
Time for managing Lean/5S (24h per month x CE)		1 328 €	1 328 €	1 328 €	1 328 €
SUM	**2 819 €**	**1 670 €**	**1 670 €**	**1 670 €**	**2 260 €**
			Total cost sum		**10 089 €**

Table 11.2 Savings from implementation

Savings type	Initial	1st quarter	2nd quarter	3rd quarter	4th quarter
Reduced overtime by 50%		355 €	355 €	355 €	355 €
5S lowered setup time		82 €	82 €	82 €	82 €
49% less annual write-offs					9 637 €
VNM - improved pricing		2 276 €	2 276 €	2 276 €	2 276 €
SUM		**2 713 €**	**2 713 €**	**2 713 €**	**12 350 €**
			Total savings sum		**20 489 €**

Tables 11.1 and 11.2 show that by one year timeline, the benefits of suggested lean changes would exceed the costs by double, helping to save funds mainly from reduced annual write-off’s due to decreased inventory and improved pricing. The largest investment would be a scheduling system and the time employees would need in order to implement and keep up with lean management in daily life. Payback period can be found by the formula [39]:

$$PB = I \div S \tag{11.5.2}$$

Where:

PB is the payback period in years;

I is the total sum of investment/costs;

S is the total sum of savings.

$PB = 10089 \div 20489 = 0{,}49\, years = 5{,}88\, months$

Considering the short payback period and unquantifiable added benefits, the selected lean tools should be considered for implementation. The savings will be even larger for the next year, with no initial costs of implementation and further improvements, but it is too preliminary to calculate that effect in numbers.

SUMMARY

To analyse the applicability of lean tools in a high-mix low-volume job shop production environment, analysis of the company that forms the bases was performed. The job shop layout with functional processes has the advantages of high flexibility, more skilled workforce, less vulnerable to machine shutdowns and lower fixed costs, but the disadvantages are high variable cost, high cost per unit, low utilisation of machines, inefficient material handling and complex planning and inventory control due to constantly high variety in demand. Analysis into strategical factors directed focus to cost, speed and dependability from the five operational performance objectives.

Company analysis gave input criteria for lean tool selection and the tools with highest score are value stream mapping, level scheduling, 5S and three of the 8 Wastes – inventory, unused potential and motion. As this kind of production environment has too many product configurations, value network was mapped instead, consisting of mapping down all the possible processes and measuring their cycle times to understand the value-added and non-value-added ratio. This analysis directed to shortcomings on pricing model, where several service prices should be updated to reflect the general trend. Level scheduling cannot be solved with existing tools, so a new software would need to be introduced in the department, to decrease problems with late deliveries and overtime work. Inventory analysis revealed high amount of profiles and components on stock well beyond their general demand. Last 24 months of demand was analysed and inventory reduction plan created, which will decrease annual write-offs, increases cash flow and efficiency. Unused potential is important in a job shop as the workface must be more flexible and skilled, thus it is recommended to train them in Lean instead of management. Motion pointed out some inefficiencies in factory layout and an improved layout was analysed, but as there are many routing combinations, further investigation would be needed before implementation. 5S revealed the common problems with workplaces, in this case the largest ones being the leftover material of different measures waiting for appropriate need. Sorting out the guideway saw showed 27% of setup reduction in cycle times and shows promising benefits for further development.

The implementation plan, measuring and control emphasizes worker engagement and lays out the implementation plan along with new KPIs and responsibility matrix. The objective is to make sure the implementation and Lean management will continue even after the first momentum.

In the calculations, the main costs were related to scheduling software, Lean training and time allocated for Lean improvements, while the most savings come from reduced write-offs from improved inventory policy, reduced overtime from level scheduling, reduced time wasted and improved pricing model. The costs by the end of first year amount to 10 089 euros while the savings to 20 489 euros, meaning the payback time will be around 6 months.

The results prove that Lean tools applicability in a job shop is limited, but still worthwhile, as there are several wastes and problems related to job shops that Lean tools can help identify and improve. As every company is different, it is recommended to start with strategic overview and analysis of the company, which will give a direction on where larger problems might lie and which tools would help the most.

KOKKUVÕTE

Kulusäästliku tootmise tehnikate kohaldatavuse analüüsi jaoks suure varieeruvusega väikesemahulises tootmiskeskkonnas analüüsiti kõigepealt ettevõtet, millel töö põhineb. Töökoja tüüpi tootmise paigutuse eelised on kõrge paindlikkus, oskuslikumad töötajad, seisakutele vähem haavatavad protsessid ja väiksemad püsikulud. Puudusteks aga kõrged varieeruvad kulud, kõrge toote omahind, seadmete madal kasutusefektiivsus, ebaefektiivne materiali liikumine ja keeruline planeerimise ja laohalduse kontroll pidevalt varieeruva nõudluse tõttu. Strateegiliste faktorite analüüs suunas fookuse maksumuse, kiiruse ja protsesside usaldusväärsuse parendamisele.

Ettevõte analüüsist saadud tulemused moodustasid kriteeriumid, mille abil valida sobivad kulusäästliku tootmise tehnikad, milleks oli väärtusahela kaardistamine, tasakaalustatud tootmisplaan, 5S ja kolm raiskamist kaheksast: varud, kasutamata potensiaal ja liikumine. Kuna sellisel tootmisviisil on väga palju erinevaid toote väärtuahelaid, siis väärtusahela asemel kaardistati väärtuse võrgustik, mis hõlmas endas kõikide võimalike protsesside kaardistamist nende keskmise tsükliajaga, et aru saada millised protsessid lisavad väärtust ja millised mitte. See omakorda juhatas puudusteni hinnamudelis, kus mitmed hinnad on kaasajastamata ja ei vasta protsessi ajakulule ja üleüldisele hinnatasemele. Tasakaalustatud tootmisplaani ei saa kahjuks olemasolevate vahenditega saavutada, mistõttu on vajalik investeering lisatarkvarasse, et vähendada tarnete hilinemisi ja ületundide arvu. Varude analüüs avaldas suure koguse profiile ja komponente, mille kogus laos oli vajadusest kordades suurem. Viimase 24 kuu varude analüüsi toel konstrueeriti plaan, millega vähendada laoseise paindlikkust ohustamata, mis omakorda vähendab mahakantavate varude hulka ning suurendab rahavoogusid. Kasutamata potensiaal on oluline just töökoja tüüpi tootmises, kus töötajate kvalifikatsioon peab olema kõrgem kui tavalises tootmises, mistõttu tuleb rohkem tähelepanu pöörata ka nende motivatsioonile ja koolitamisele. Sellest tulenevalt on soovitus antud juhul kulusäästliku tootmise koolitus läbi viia just tootmistöötajate seas, mitte juhtkonna nagu tavaliselt. Liikumine tehases avaldas küll mõned ebaefektiivsused tehase plaanis, aga kuna erinevaid tellimuste kombinatsioone on väga palju, siis antud tulemuste juurutamine võib endaga kaasa tuua osade marsruutide pikenemise ning seega vajab sügavamat analüüsi enne juurutamist. 5S avaldas levinud probleemid töökohtades, milleks antud juhul olid profiili ja juhikute sae ümber asetsevad erinevates pikkustes toodete jäägid, mis tuleb ära kasutada ja mis ootavad sobivat kliendi nõudlust. Juhikute jääkide riiulite sorteerimine ja süstematiseerimine vähendas kogu tsükliaega 27% võrra ning 5S edasisel arendamisel väheneb kogu tsükliaeg veelgi enam.

Juurutusplaan, mõõtmised ja jälgimine esitab leitud tehnikate juurutamiseks ajalise plaani, tulemusindikaatorite koondtabeli ning vastutusmaatriksi, pidades silmas töötajate kaasahaaratust. Eesmärgiks on pikeajaline kulusäästlike tehnikate juurutus ja areng, mis ei vaibu peale esimesi edusamme.

Tasuvusanalüüs näitas, et põhilised kulud on seotud planeerimisprogrammi, kulusäästlike tehnikate koolituse ja parenduste jaoks pühendatud ajaga. Põhiline sääst tuleneb vähendatud mahakandmistest tänu uuendatud varude juhtimisele, vähendatud ületundidest tänud planeerimisprogrammile, vähendatud ajakulust tänu 5S'ile ning parendatud hinnastusmudelist. Esimese aasta plaanis on kogukulude summa 10 089 eurot ning kokkuhoid 20 489 eurot, mis tähendab et tasutusaeg on umbes kuus kuud.

Töö tulemused tõestavad, et kulusäästliku tootmise tehnikate kohaldatavus töökoja tüüpi tootmises on küll limiteeritud, ent siiski väärtuslik, kuna aitab tuvastada ja parendada erinevaid probleeme ja raiskamisi. Kuna iga ettevõtte on erinev, on soovitav alustada ettevõtte strateegilisest ülevaatest ja analüüsist, mis suunab suuremate probleemide juurde ja aitab leida kohased kulusäästlikud tehnikad nende lahendamiseks.

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APPENDICES

Appendix 1: Annual report: Introduction

Tegevusaruanne

Sissejuhatus

2020. aastal jätkas Alas-Kuul AS traditsioonilise äritegevusega, müües tööstusseadmieid ja teostades neile tehnilist hooldust. Kindlustati saavutatud turuosa ja leiti uusi kliente. Ettevõttel on müügikohad Tallinnas, Tartus, Pärnus, Narvas, Rakveres, Viljandis ja püsiv tegevuskoht Riias.
Tegevuskeskkonna üldine areng soosib ettevõtte arengut, äritegevuses ei esine hooajalisust ning tsüklilisust. Ettevõtte juhtkonna hinnangul ei kaasne tegevusega olulisi keskkonna- ja sotsiaalseid mõjusid.

Ülemaailmne Covid-19 pandeemia mõjutas Alas-Kuul AS 2020. aasta majandustegevust, müügitulu langes võrreldes 2019. aastaga 12 protsenti, ning vähendati töötasusid 20 protsendi võrra. Riigiabi Alas-Kuul AS ei vajanud.

Tulud, kulud ja kasum

2020. aastal moodustas Alas-Kuul AS müügitulu 19 278 tuhat EUR-i, sellest tööstustarvikute müük oli 96 protsenti ja teenuste müük 4 protsenti.
Kogu müügitulu vähenes 12 protsenti, mitmesugused tegevuskulud vähenesid 2,9 protsenti.
Alas-Kuul AS müügitulust teeniti Eestis 94 protsenti.
Aruandeaastal oli aktsiaseltsi ärikasum 1 161 tuhat EUR-i, 2019. aastal oli see 2 032 tuhat EUR-i.

Peamised finantssuhtarvud			
		2020	**2019**
Müügitulu	tuhat EUR	19 278	21 788
Tulu kasv	%-des	-12	2
Puhaskasum	tuhat EUR	864	1 876
Kasumi kasv	%-des	-54	72
Puhasrentaablus	%-des	5	9
Lühiajaliste kohustuste kattekordaja	kordades	2	3
ROA	%-des	8	18
ROE	%-des	14	30

Suhtarvude arvutamisel kasutatud valemid:

Käibe kasv (%) = (müügitulu 2020 – müügitulu 2019)/ müügitulu 2019 * 100

Kasumi kasv (%) = (puhaskasum 2020 – puhaskasum 2019)/ puhaskasum 2019 * 100

Puhasrentaablus (%) = puhaskasum/ müügitulu * 100

Lühiajaliste kohustuste kattekordaja (kordades) = käibevara/lühiajalised kohustused

ROA (%) = puhaskasum/ varad kokku * 100

ROE (%) = puhaskasum/ omakapital kokku * 100

Appendix 2: Minitec sales revenue 2019

Sales Summary

Alas-Kuul AS
28.04.2021 11:07
Created by: Martin Hanson

This is a cached report that was created on 28.04.2021 11:07. Refresh report.

Filters:	
Period:	01.01.2019 – 31.12.2019
Location:	MINITEC warehouse
Gift cards:	Exclude untaxed gift card sales
Currency:	EUR

	net sales total	VAT: 20% (20%)	sales total with VAT
January 2019	13 832,86	2 761,77	16 594,63
February 2019	137 551,01	27 470,14	165 021,15
March 2019	72 958,16	14 591,63	87 549,79
April 2019	109 147,69	21 829,54	130 977,23
May 2019	103 726,17	16 986,25	120 712,42
June 2019	113 057,68	21 710,50	134 768,18
July 2019	170 763,45	34 152,69	204 916,14
August 2019	145 227,23	29 039,99	174 267,22
September 2019	157 432,87	31 486,57	188 919,44
October 2019	159 206,07	27 340,79	186 546,86
November 2019	59 545,27	8 306,04	67 851,31
December 2019	114 728,35	9 934,70	124 663,05

net sales total:	**1 357 176,81 €**
net sales total: 0% (0%)	**129 123,76 €**
net sales total: 20% (20%)	**1 228 053,05 €**
VAT: 20% (20%)	**245 610,61 €**
sales total with VAT:	**1 602 787,42 €**

Appendix 3: Minitec sales revenue 2020

Sales Summary

Alas-Kuul AS
28.04.2021 11:06
Created by: Martin Hanson

This is a cached report that was created on 28.04.2021 11:06. Refresh report.

Filters:

Period:	01.01.2020 – 31.12.2020
Location:	MINITEC warehouse
Gift cards:	Exclude untaxed gift card sales
Currency:	EUR

	net sales total	VAT: 20% (20%)	sales total with VAT
January 2020	84 927,40	16 985,48	101 912,88
February 2020	68 483,97	13 696,79	82 180,76
March 2020	96 972,06	19 394,41	116 366,47
April 2020	80 197,74	12 940,44	93 138,18
May 2020	48 059,42	9 611,88	57 671,30
June 2020	77 353,90	8 189,40	85 543,30
July 2020	47 004,85	9 400,97	56 405,82
August 2020	22 909,39	4 581,88	27 491,27
September 2020	85 464,74	10 836,10	96 300,84
October 2020	51 438,49	9 268,86	60 707,35
November 2020	162 015,14	12 320,17	174 335,31
December 2020	95 375,55	16 573,32	111 948,87

net sales total:	**920 202,65 €**
net sales total: 0% (0%)	**201 204,11 €**
net sales total: 20% (20%)	**718 998,54 €**
VAT: 20% (20%)	**143 799,71 €**
sales total with VAT:	**1 064 002,36 €**

Appendix 4: Measured Cycle Timetable

#	Profile Saw					Drilling		
	S/U	**C/T ≤45**	**C/T 45x90**	**C/T <90x90**	**C/O**	**S/U**	**C/T**	**C/O**
1	80	12	23	25	19	72	38	9
2	205	11	18	27	7	65	39	11
3	55	12	21	25	9	70	37	14
4	110	14	17	26	23	69	35	12
5	135	13	22	23	21	58	41	15
6	92	9	24	24	6	65	38	17
7	70	11	20	27	8	80	40	8
8	186	10	19	26	9	75	39	12
9	69	11	21	28	17	77	37	8
10	102	12	19	26	13	68	40	14
Median	97	11,5	20,5	26	11	69,5	38,5	12
Percentile	**128,75**	**12**	**21,75**	**26,75**	**18,5**	**74,25**	**39,75**	**14**

#	M8 Threading			Guideway saw				
	S/U	**C/T**	**C/O**	**S/U**	**C/T <20mm**	**C/T 20-35mm**	**C/T >35mm**	**C/O**
1	3	31	5	410	21	35	64	41
2	5	27	4	349	23	47	58	50
3	4	28	6	140	40	60	84	38
4	3	30	4	391	24	32	63	52
5	6	29	5	250	18	38	59	48
6	4	30	3	332	19	37	91	46
7	5	27	7	152	42	36	68	56
8	4	30	4	421	19	32	78	52
9	5	31	7	363	34	42	82	44
10	4	27	5	281	22	57	65	37
Median	4	29,5	5	340,5	22,5	37,5	66,5	47
Percentile	**5**	**30**	**5,75**	**384**	**31,5**	**45,75**	**81**	**52**

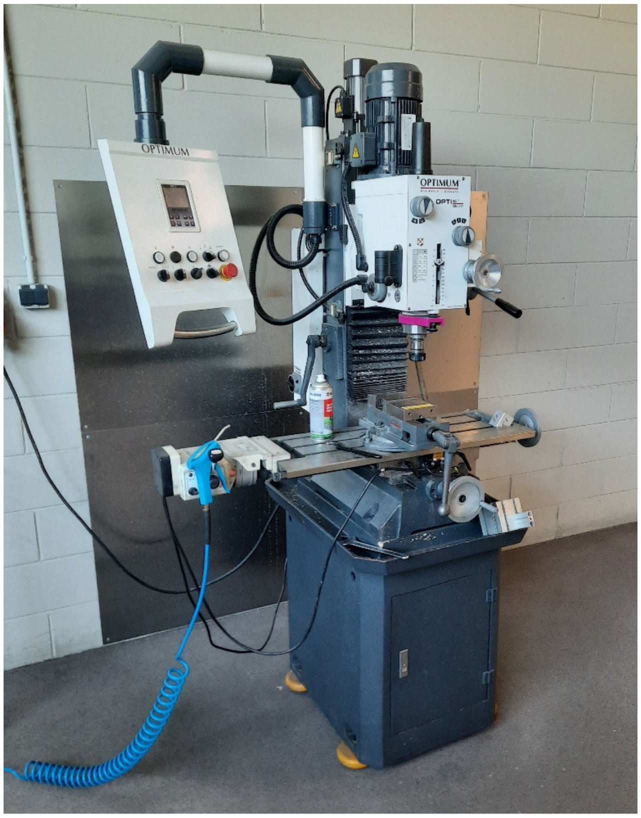
#	Milling			Components		Format saw			Assembly		Packing	
	S/U	**C/T**	**C/O**	**C/T**	**C/O**	**S/U**	**C/T**	**C/O**	**S/U**	**C/T**	**S/U**	**C/T**
1	247	50	25	12	2	192	35	27	120	3600	35	135
2	206	18	8	7	3	183	62	35	128	3600	62	250
3	172	120	12	20	2	205	46	19	65	3600	32	123
4	209	45	15	21	1	201	29	22	260	3600	251	328
5	267	12	29	8	3	142	52	28	59	3600	185	1200
6	191	62	9	7	2	394	54	20	485	3600	65	50
7	145	35	19	15	4	156	69	32	68	3600	254	1102
8	175	11	10	11	3	242	34	31	325	3600	158	95
9	189	20	28	19	2	169	41	28	275	3600	235	276
10	201	58	15	6	3	177	46	29	142	3600	64	325
Median	196	40	15	11,5	2,5	187,5	46	28	135	3600	111,5	263
Percentile	**208,25**	**56**	**24**	**18**	**3**	**204**	**53,5**	**30,5**	**271,3**	**3600**	**222,5**	**327,3**

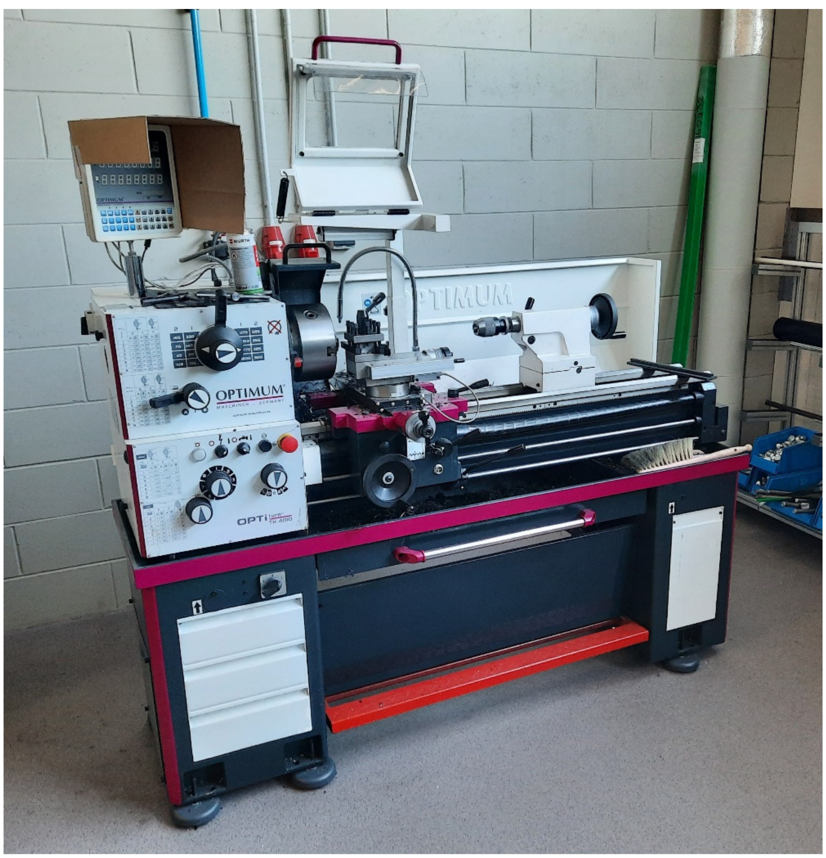
GRAPHICAL MATERIAL

Profile and Guideway saw

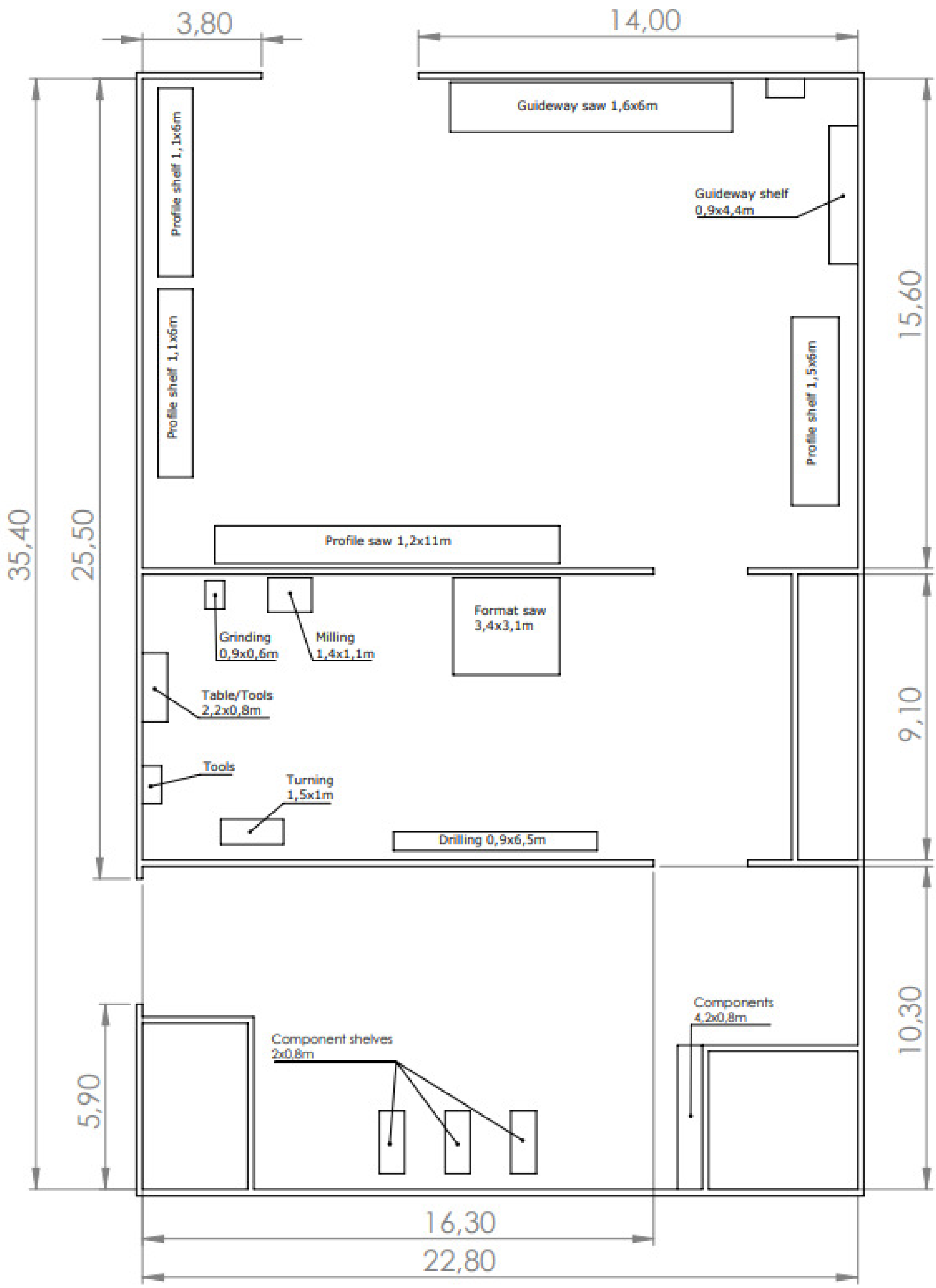
Drilling machine and format saw

Milling and turning machine



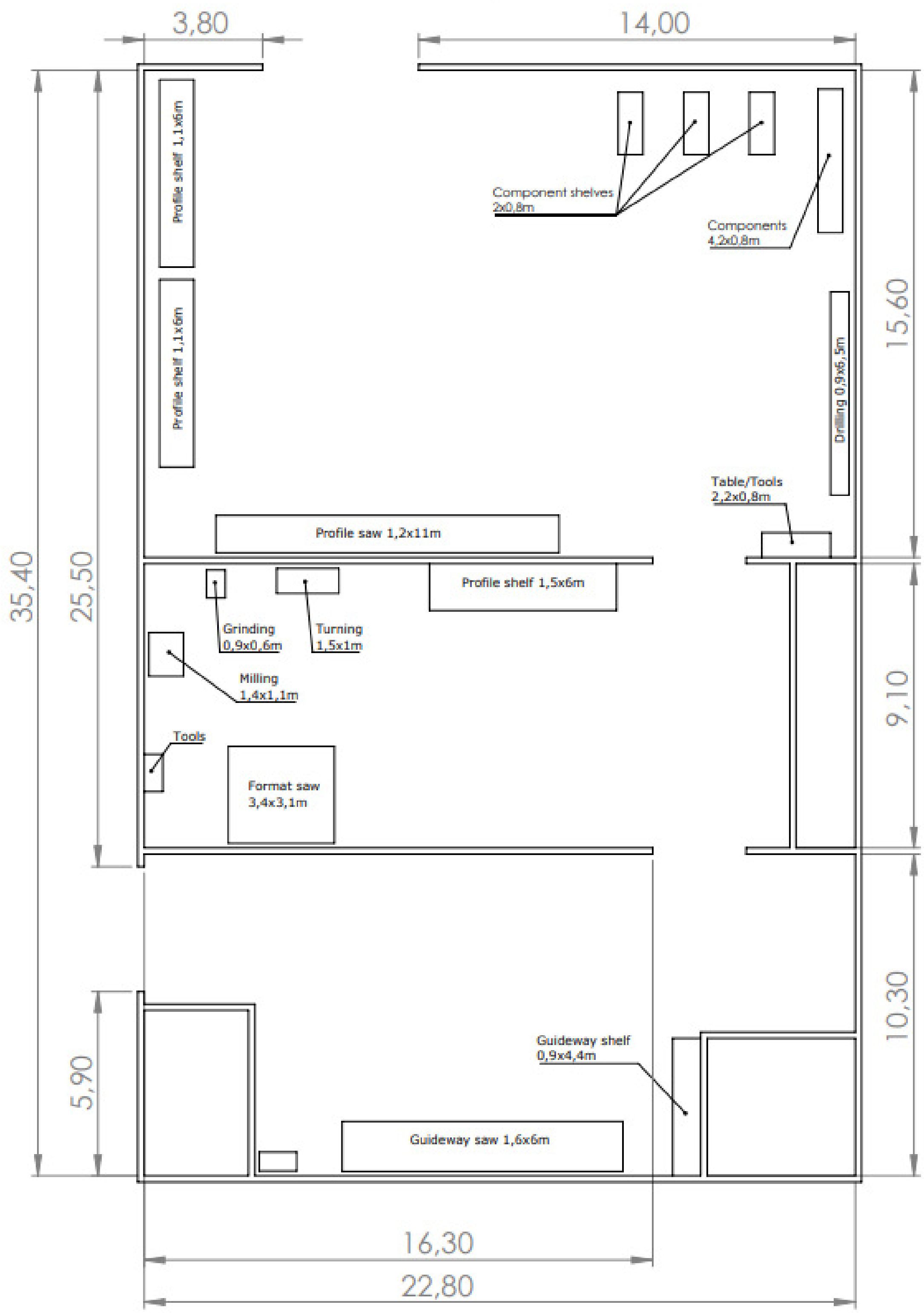


Shop Floor 1



All dimensions in meters unless specified otherwise.

Shop Floor revised



All dimensions in meters unless specified otherwise.