TALLINN UNIVERSITY OF TECHNOLOGY

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MASS CUSTOMIZATION SYSTEM DEVELOPMENT FOR PRODUCTION LINE UTILIZATION IMPROVEMENT IN ENSTO

Author applies for academic Master of Industrial Engineering and Management degree

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Author's Declaration

I have written the Master's Thesis independently.
All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's Thesis is completed under .... supervision

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Master's Thesis is in accordance with terms and requirements "......."...................20….

Supervisor …....................................... signature.

Accepted for defence

.... chairman of defence commission

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Summary

ENGLISH

This work is intended to give a solution to the low usage of the mass customization system that was developed some years ago for Ensto.

As a trainee, an on-site learning of how the machine works has been done. The different issues and problems, and the workers concerns about it were understood. A long time of the project has been dedicated to understand the system better and to detect the cause of the failures. To understand the system as a whole, it has been thoughtfully analyzed. As each of the components, the PLC logic program, the code of the program, and all the electric circuit is part of a complex system, it requires that all the components are correctly working.

After the analysis of the machine, the situation of the machine was studied, to see how it was working and what problems were the most recurrent. During this time, different studies helped to compare the ideal VS the real situation.

Then, with the knowledge of the machine and its situation, solutions were thought to put the machine to work. The changes have involved software changes, component replacement, new systems introduction, new approaches of manufacturing etc.

During all the time a study of the different materials, research and texts relating to process improvement and mass customization have been used to gain knowledge in the topic and apply it to the Ensto case, that way good practices and things to improve were more clear.

At the same time, the used software has been analyzed, and other possibilities have been studied. That study was used to understand the reasons why the customers were not using the software owned by Ensto as much as it was intended in a beginning.

To finalize, and after giving some guidelines, a conclusion, and future possibilities of the mass customization system have been addressed, to help the company in the long term vision.

ESTONIAN

Selle töö eemärk on anda lahendus miks kasutatakse liiga vähe kohandamise süsteemi, mis arendati aastaid tagasi Ensto poolt. Praktikandina olen selgeks teinud masina tööpõhimõtted, erinevad probleemid ja tööliste mured masina kasutamise kohta on arusaadavad. Projekti käigus on palju aega kasutatud masinast arusaamiseks ja rikete tuvastamiseks. Et täielikult süsteemist aru saada on seda tähelepanelikult analüüsitud. PLC loogikaprogramm, programmi kood ja elektriskeem on osa keerukast süsteemist, mis nõuab, et kõik komponendid töötaksid õigesti.

Peale masina analüüsi saime teada masina olukorra, kuidas see töötab ja millised probleemid on kõige korduvamad. Erinevad uuringud (vigade esinevus, masina täpsus, võrdlus teiste masinatega, jne) aitasid võrrelda ideaal ja reaalset olukorda.

Mõeldi lahendused kuidas masin tööle saada.

Lahendused, mis töösse pandi on järgmised:

- Tarkvara muudatused, et muuta tooriku nullpunkte.
- Vahetati välja vigased komponendid.
- Ehitati süsteem, mis teatab töötajat millal laadida konveierit.
- Rakendusele võetud erinevad uued tootmismeetodid.

Kõikide nende muudatuste jaoks kasutati teadmisi elektroonikast, mehaanikast, kvaliteedijuhtimisest, tootmisjuhtimisest ja Lean tootmisest. Peale muutuseid tehti uued analüüsid, et veenduda muudatuste toimimises. Kasutusesse võetud PDCA tsükkel. Kõik analüüsid ja uuringud andsid teadmised roboti kohta ja tänu sellele saab need teadmised edasi kanda töölistele, et nad saaksid masinat korrektselt kasutada. Valmis kasutusjuhend Eesti keeles ja hooldusosakond on teadlik vigadest ja nende tekkimise põhjustest.

Uurimise ajal sai läbi töödeldud erinevaid tekstimaterjale, mis on seotud protsesside parendamise ja mass kohandamisega, et saada teadmisi nendel teemadel ja kasutada neid teadmisi Ensto teemal.

Analüüsiti ka kasutusel olevat tarkvara, et aru saada miks kliendid ei kasuta Ensto enda tarkvara nii nagu oli algul plaanitud. Mõned põhjused selleks on ,et kasutajaliides on vigane, limiteeritud disaini vüimalused jne.

Järgneb eesmärkide võrdlus saavutatud tulemustega.

Tulevikuks juhul kui uue genartsiooni massi kohandamise süsteem (sisaldades robotit ja tarkvara) disainitakse on valminud nõuete nimekiri, et aidata ettevõttel saavutada pikemas perspektiivis mass kohandamise teenust klientidele..

Contents

Abbreviation list

- BOM: Bill of materials
- CAD: Computer-aided design
- CNC: Computer numerical control
- ERP: Enterprise resource planning
- FMS: Flexible manufacturing system
- MT-100 or Cuboflex: Customization robot cell in Ensto
- PPM: Defective parts per million
- SMED: Single-minute exchange of die
- SWE: Shared worker environment
- T_p: Average manufacturing cycle time per work unit

Introduction

Company

Ensto is a family business which was established by Ensio Miettinen in the year 1958. Company is specialized in the development, manufacturing and marketing of electrical systems and supplies for the distribution of electrical power and electrical applications. Company is committed to sustainable development and its goal is to be the world's leading company in green energy efficiency and distribution. Ensto products are environmentally friendly by contributing to minimum carbon footprint due to collection/reuse of wastes and efficient use of resources.

Company has 1,670 employees working in sales/production sites located in 20 different countries along Europe and Asia (April, 2014). There are altogether 7 production sites of Ensto, located in Finland, Russia, Estonia, Italy, France, Spain and India. Headquarter is located in Porvoo, Finland. Ensto's yearly turnover is about 280 million euros (2013, see Graph 1) and it exports products into more than 80 countries along the globe.

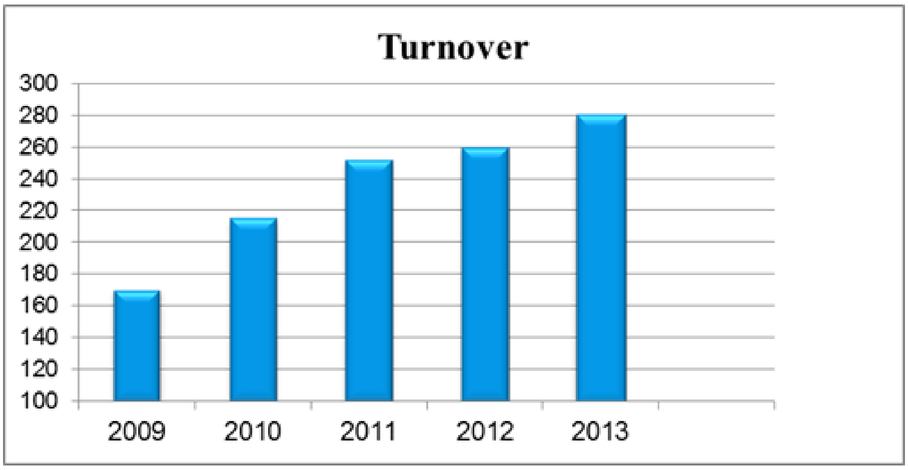

Figure 1:Ensto turnover during 2009-2013

Ensto Ensek AS is a group of Ensto which is located in Estonia. Ensto Ensek AS has three factories: injection moulding factory in Tallinn, assembling factory and metal factory in Keila. In April 2014 Allpilux Oy was bought by Ensto Group Oy and since then Allpilux's Paide factory is also part of Ensto.

There are 5 most important values for Ensto:

Ensto employees because they are related to everyday actions, are visible at everyday operations and are related to customer relationships.

Trust capital which means that Ensto has earned and will continue to earn its trust among the customers, employees and other stakeholders through the loyalty of relationships between different parties.

Excellence towards performance by accepting new challenges, learning continuously and improving the performance.

Respect for the customers, colleagues and other stakeholders by honest relationships and collaboration.

Encouraging creativity by the contribution of thinking and acting innovatively and being open-minded to new ideas.

Business units

There are three key business units of Ensto: Industrial Solutions (Ensto IS), Ensto Building Technology (Ensto BT) and Ensto Utility Networks (Ensto UN).

Industrial solutions (which represent the 12% of the company share) provides enclosing systems and industrial components for demanding environments [1]. Ensto building technology (with 37% of the share) offers solutions in the field of integrated building technology [1] and finally the biggest business units, with a 57% of the share, Utility networks, offers a range of power distribution solutions in the core of green thinking [1]

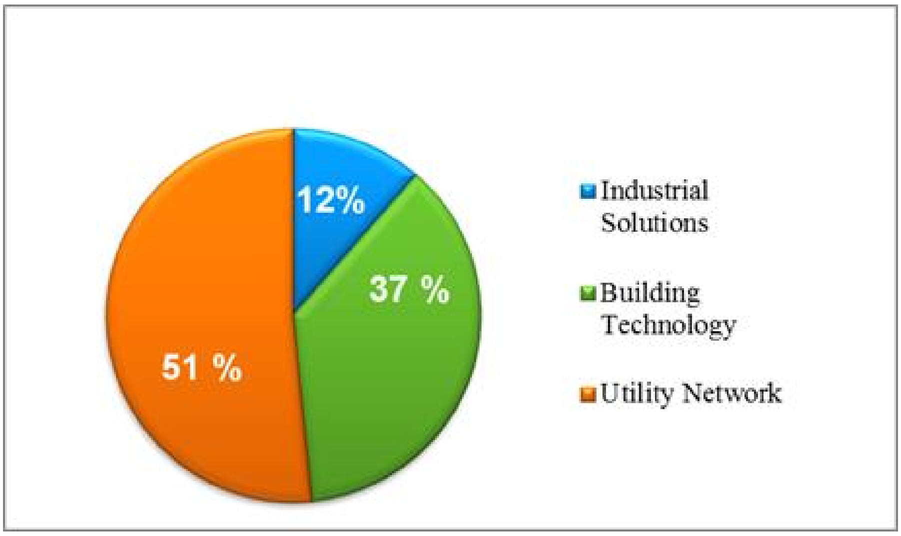

Figure 2: Ensto key business units and their share (%) of all the key business areas.

Ensto Industrial Solutions (IS) are customer-specific solutions for demanding environments. Along IS there are mainly enclosing solutions made of plastics and metals (see Visual 2). Named products require high degree of protection (for example explosion protection), long lifespan and extreme durability ensuring clients safe working environments at extreme conditions.

Figure 3: Thermoplastic and metal enclosures [1]

Ensto Building Technology (BT) is another key business area which includes innovative and energy efficient electrification and ventilation solutions for residential and non-residential buildings. This business area includes for example energy efficient lightning, wiring accessories, electrical heating solutions etc. (see examples on Visual 3).

Ensto Utility Networks (UN) provides solutions for reliable electricity distribution networks. Solutions are offered in 4 main areas: overhead line networks, underground cable networks, power quality and network automation. UN includes wide variety of products, for example load break switches, fault indicators, voltage boosters and circuit breakers. These products have to stand the most demanding and varying conditions.

Problem definition

During this master thesis, the improvement of the utilization of the mass customization system is the goal.

For the customization purposes, different machining cells are used. Three of them are CNC commercial machining cells. As part of an attempt to achieve mass customization, a special robot cell was ordered in 2008 to the Finnish company MAG (Master Automation Group), this cell was intended to serve for the Small-medium batches giving enough flexibility in manufacturing.

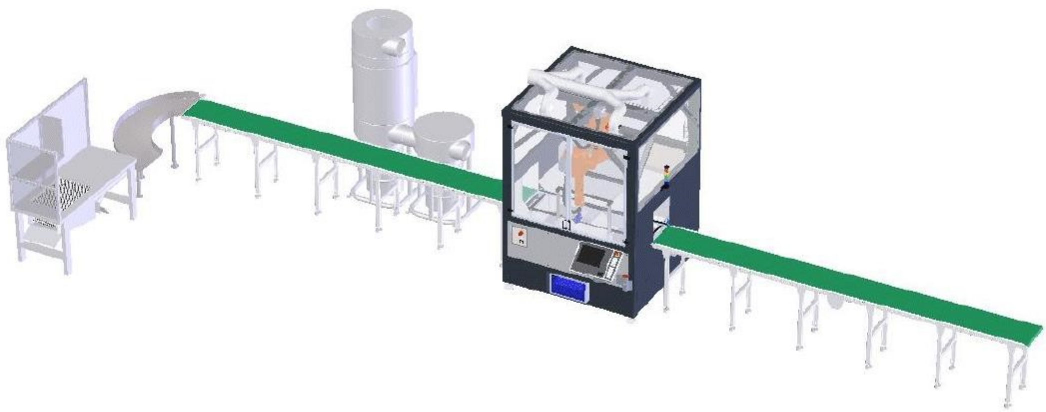

Figure 4: Robot cell by MAG

But since the project started in 2009, the utilization has not been as high as expected. To have an idea of the necessity of improving the utilization rate of the robot cell (from now on it might be referred to as MT-100). Data of the machining cells from the last two year has been taken from the arrow software assembly database. MT79, MT80 and MT82 are Fanuc CNC machines.

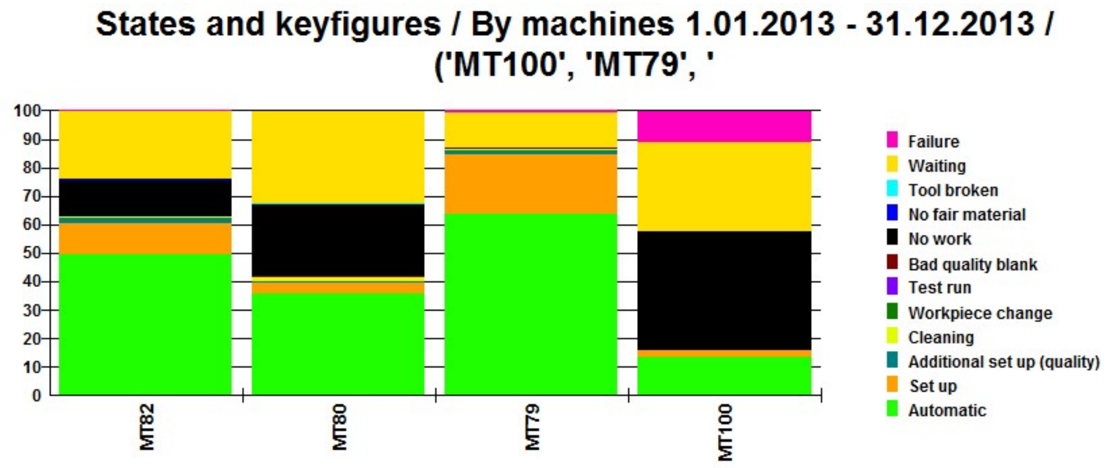

Figure 5: Utilization of customization cells in 2013

With almost a 10% of the available time being in failure mode, the utilization rate is low when comparing with the other cells.

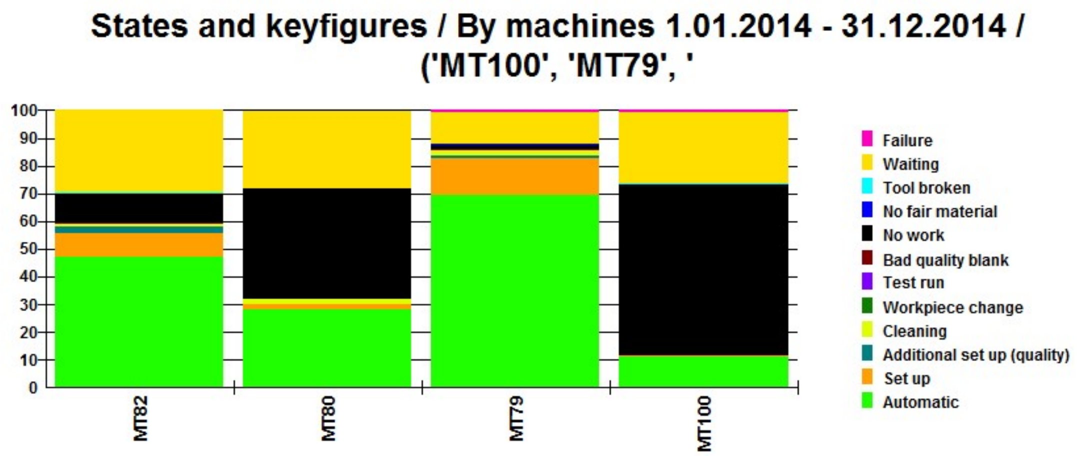

Figure 6: Utilization of customization cells in 2014

In 2014 the failure percentage dropped, as well as the utilization. As the workers and production planners cannot rely on a machine that in 2013 was almost 10% of the time stopped due to failures as seen in Graph 4.

The utilization rate is about 5 times lower in the MT100 (robot cell) than the most used CNC machine. There are also two more things that should be noted about the robot cell:

- The set up times are very low, if not inexistent when comparing to the other machining centers.
- The availability is slightly lower when comparing to the other machining centers

This data sustains the need to improve the robot cell, as an increment would mean to be able to use the robot cell to customize small-medium batches, thus reducing the lead time for orders.

Object description (Cubolink + Cuboflex)

The main parts of the system are the robot cell, the two conveyors for the input and output of the pieces, the dust filtration system and the Touch screen computer, where the needed program can be loaded into the robot.

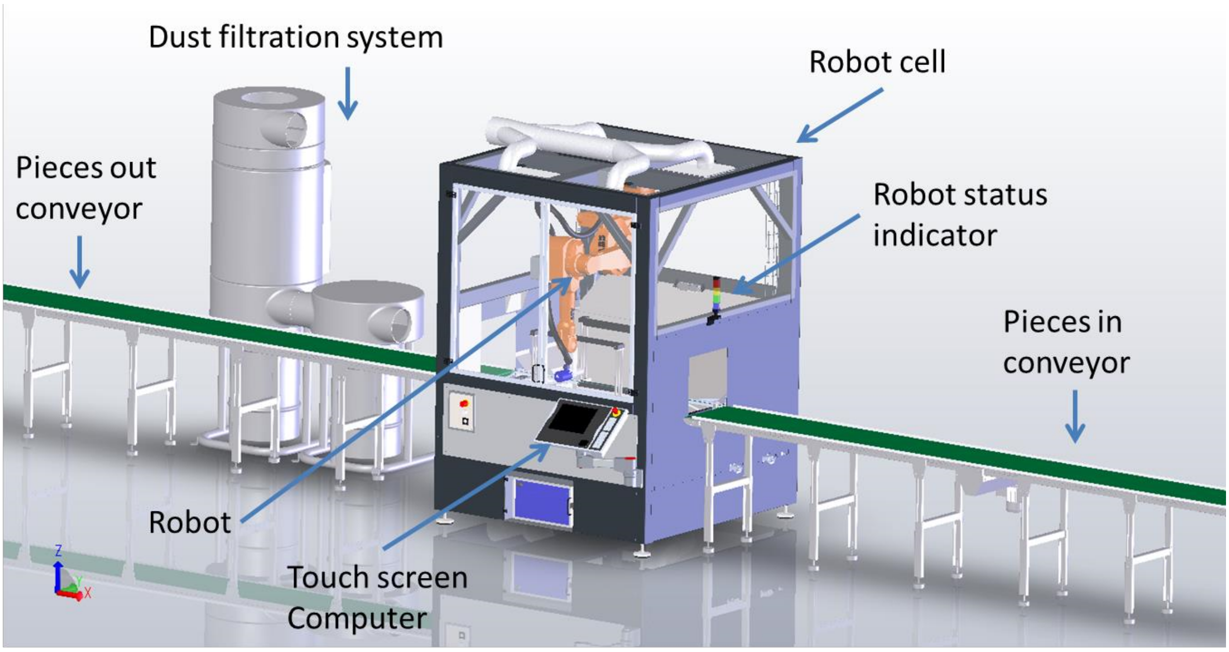

Figure 7: Cuboflex robot cell layout

Inside the robot cell, a jig system can be found to accommodate the different sizes of enclosures that the robot cell can handle, once the parts are fixed in the jigs, the robot takes the needed tool and starts drilling the box. The feed in and feed out conveyors are used to put the enclosure in the jig and to take it out.

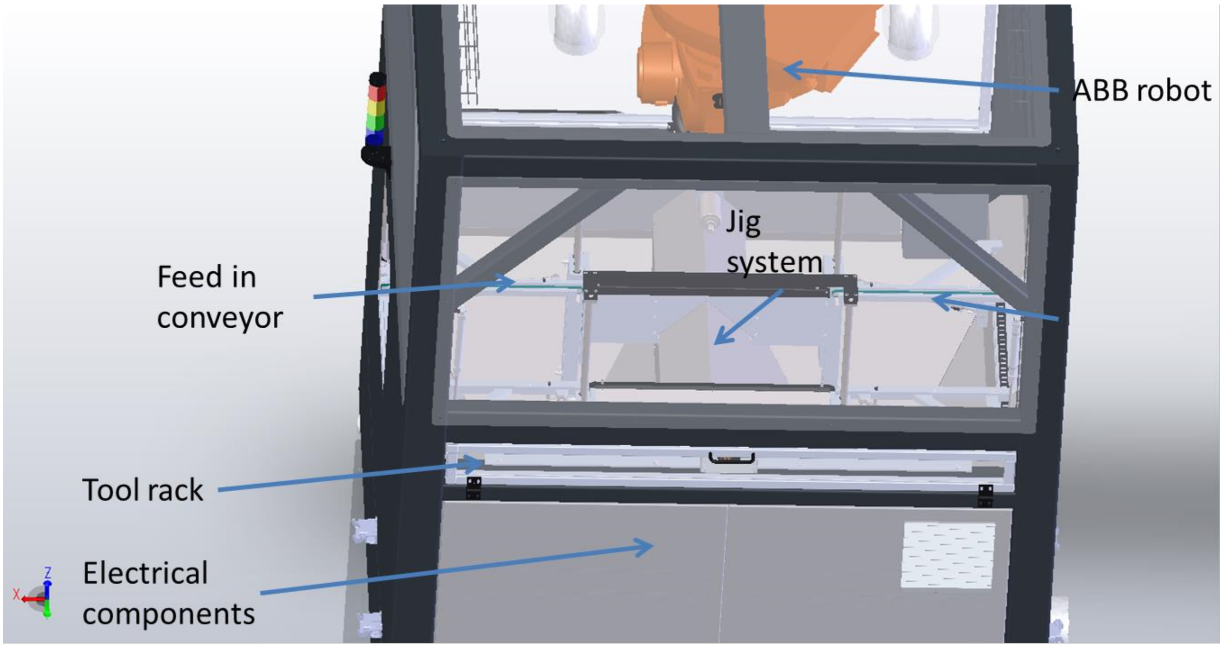

Figure 8: Inside the robot cell

The jig system is composed by a movable and a fixed part, the movable part moves along thanks to a servomotor adjusting to the width of the enclosure. The clamps, actioned by air cylinders fasten the enclosure in the X and Z axis (see Figure 8) the cylinders are stopped when a certain pressure is reached.

In the other hand the stoppers go up in order to position the enclosure in the right position (depending on the sides that enclosure has to be machine will be in one side or the other of the jig system). Finally the belts help the enclosure move along the jig, with help of another cylinder that goes up to help to obtain the movement along the track (see Figure 9).

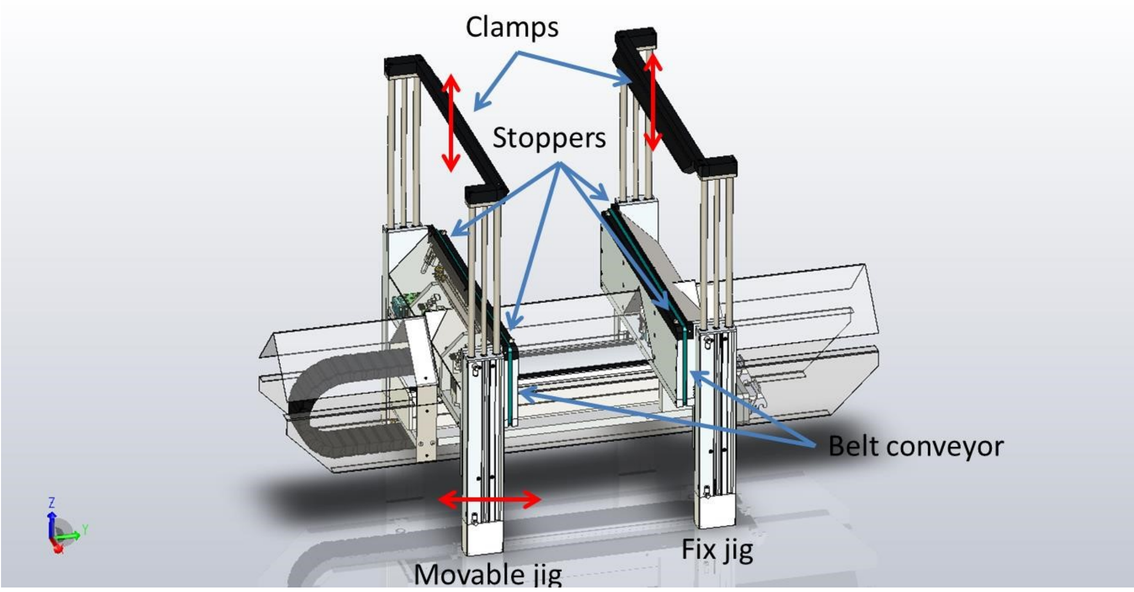

Figure 9: Jig system

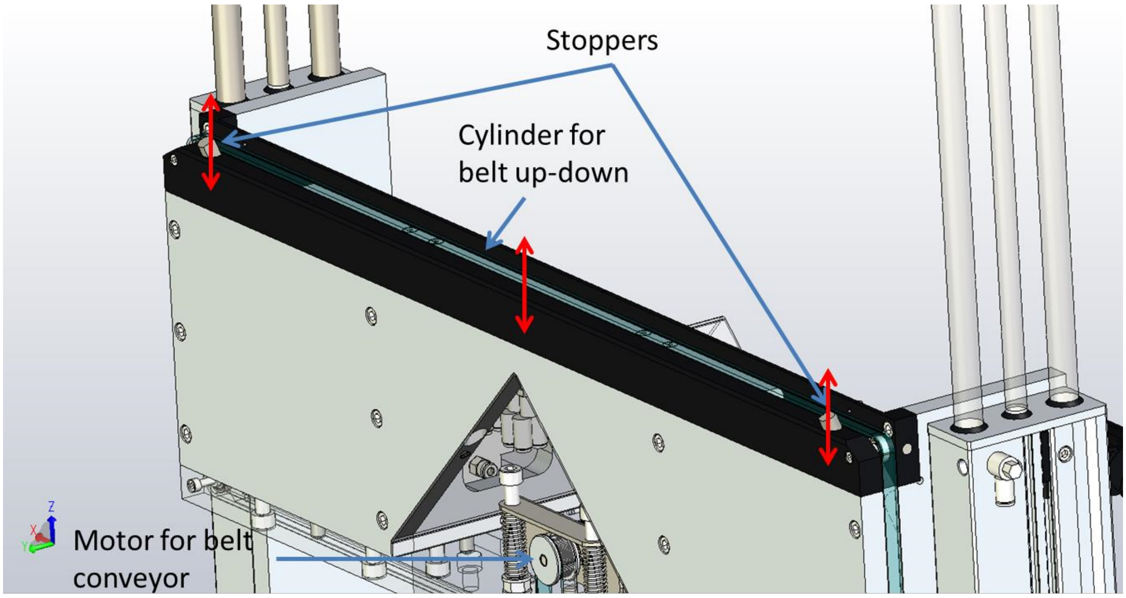

Figure 10: Belt system in Jig

In the tool rack, the different tools needed for different operations are located. After changing the tool, the length of the tool is measured, to make sure that it is the right tool, this way, it prevents problems when tools are not in the right position (which might result in a dangerous collision) and it is also used to detect if the tool has been broken.

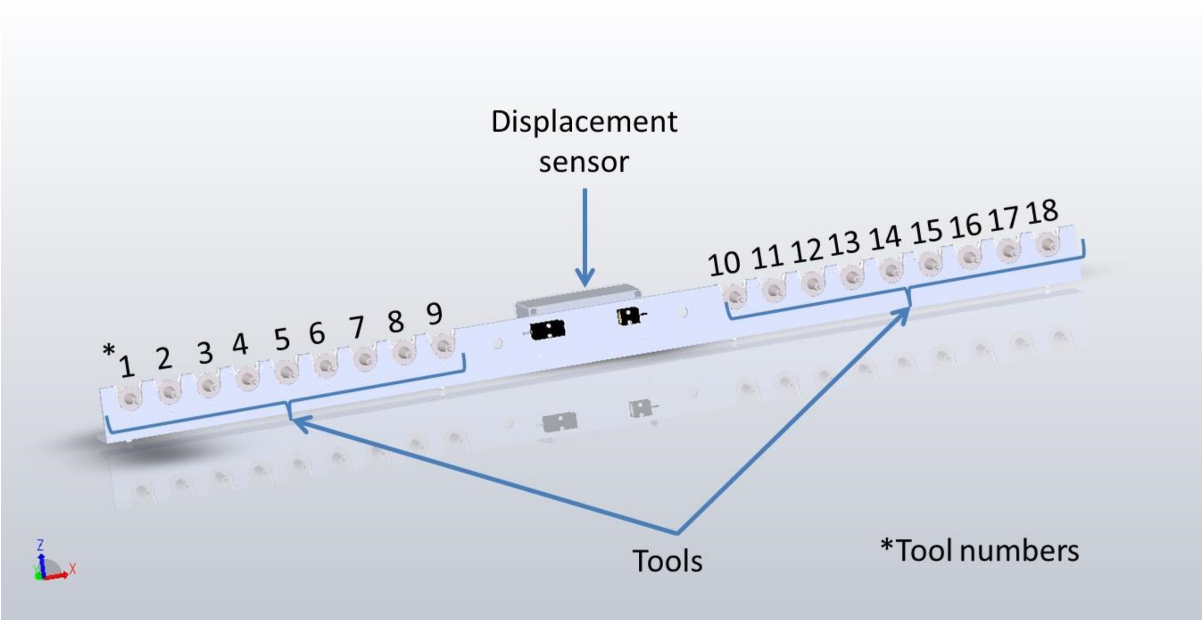

Figure 11: Tool rack

Problem solving methods

To understand this situation, the first step was to talk with the workers, after that a study of the machine and the performance was carried. After this analysis some possible causes for this low utilization were found.

After understanding the machine failures, a literature research has been done to understand how a proper customization system should be built and how it can be improved.

Preventing the failures by making the users understand the know-how (Advanced skills), and offering an overview of the know-why (systems understanding) will help to use the technology better. Finally and completing the classification of knowledge management [2], care why (Self-motivated creativity) will be seek, by offering a hint of the future possibilities, in order to help the company in future strategic decisions.

Work objectives and tasks

Main objective is to improve the utilization of the customizing robot cell, hence following tasks have been designed to complete during the master thesis

- Review existing literature on mass customization systems and process improvement.
- Improve process capability
- Improve production time
- Propose new process workflow
- Guidelines for future robot cell generation

Existing literature and theory

Manufacturing today is not what it used to be, the globalization (being the main enablers: transportation and communication improvements, consumer awareness and improved political relationship) has resulted, in an ever-increasing expectation from the side of the customers in the global competitive market [3]. Slack et al. Defines 5 operations performance objectives in order to be competitive in his Operations management book [4]:

- Cost: Ability of producing at low costs
- Quality: Producing within specifications without errors
- Speed: Rapid response to customer demands (short lead time)
- Dependability: Ability to deliver product in accordance with promises
- Flexibility: Ability to change operations, can comprise four aspects
    - Change in production volume
    - Change in time to produce
    - Change of mix of products or services provided
    - Ability to innovate and introduce novel products and services

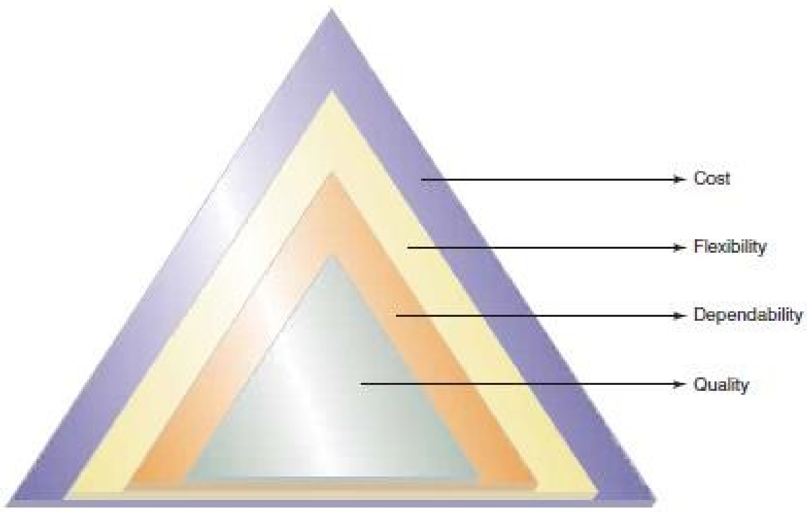

Figure 12: The "sandcone" model of operations excellence. [4]

Those are some essential needs of the modern companies if they want to stay competitive. For that reason, new philosophies are trying to fulfill those requirements, example of this are the lean approaches, including Total Quality Management and Mass customization. Some of the lean approaches will be analyzed and used during the thesis, but first mass customization process will be analyzed.

Mass customization

Mass manufacturing is a popular topic nowadays, in a context where is considered as a main business strategy focusing on a tailored design and development of individual products that fulfill the customer needs. [5]

The key for mass customization is flexibility, or high variety while maintaining high speed, quality and acceptable cost. Another key ability is to be able to align the organization with its customer needs [6]. This represents a complex case, which would be impossible to think about some years ago without actual technologies.

This represents an opportunity, as the added value provided by the mass customization can be quantified as an extra price, especially in additional market niches that standard product wouldn't target [7]. This phenomenon can be observed in Figure 13.

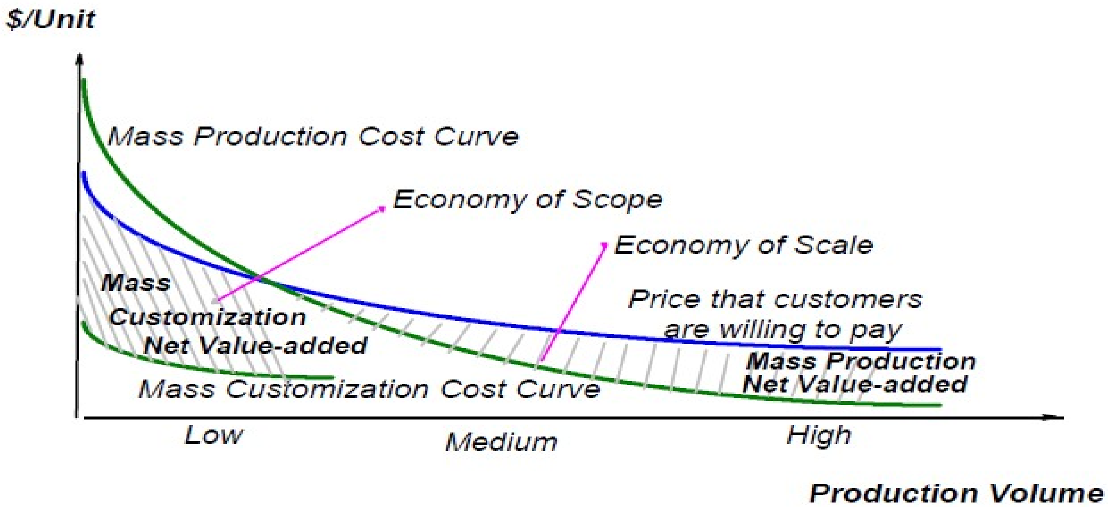

Figure 13: Mass customization: economic implications [8]

As well as the complexity of the flexibility of mass customization is a problem, it is difficult to understand the real needs of the costumers (designing correctly the software where they can capture what they want in an effective and fast way, that will add value to the customer), and finally it has to be understood that not all people is willing to pay to have the products they want customized [7].

There are different ways to represent graphically the mass customization level, but in this case three required capabilities for mass customization will be used [6]:

Solution space Development: Identifying needs of customers and once understood, company can define its own solution space. A typical tool for that purpose is a CAD, with an easy to use interface, library and basic modules, is a useful way to understand the needs of different types of individual customers at low cost. Big data could be used here to analyze the data and learn about customer preferences, thus eliminating not used options and making the most popular more visible in order to gain sales.

Robust process design: Variability in customers' requirements should not worsen the capabilities of operations and supply chain, thus an appropriate process design is needed, one possibility is to use flexible automation, and this is done by increasing digitalization.

Choice navigation: After some experiments, phycologist Barry Schwartz, argued that having too many choices reduces the value instead of increasing it [8], because of that reason navigation in the mass customization should be as simple as possible. A possible approach could be "assortment matching", where software automatically builds configurations according to their characteristics of sets of options. Also, software can have a built-in database, so past designs are saved, and those can be redesign and changed again, or recommendations, based on previous searches, might appear for each specific user.

For achieving the just described three required capabilities, three main elements of mass customization are needed [7].

Elicitation: Mass customization requires a tool where the customer can embody its needs, usually called configurator. Still in some situations the customer feels overwhelmed by too many selections and ends up giving up and exits the configurator without buying anything, as stated before, the Solution space and Choice navigation are important capabilities, in order to make sure that customer needs are understood, the design of the configurator should give as much value to the customer as possible. For giving customers what they want, first you have to learn/study what is that they want (Solution space development)

Process flexibility: In every industry only some stages are sufficiently flexible, process information being the most flexible one. Starting from simple digitalized cutting operations (1 axis) to complex milling robots (3 or more axis), technology nowadays grants a huge flexibility in the process with almost instant pattern switching.

Logistics: It is a must that the information of customer-specific information and some additional information moves along all the supply chain. An example case could be a robot that makes some custom made holes, but then some humans have to receive the information of which components to assembly and where, as well as the packaging line should receive information and finally the address info should be provided to deliver the goods properly. This is the element that will make the batch arrive on time, with correct components and where is supposed to arrive.

As it can be seen the most critical points in mass customization is to know the customer needs, having a proper IT system where customer can simply customize and show its needs and finally some technology capable of having enough flexibility to handle the entirely different requests.

But all the approaches to mass customization are not the same, neither the forms of products developed [9]. 4 Approaches to mass customization are differentiated:

Collaborative customization: The customer is involved in the design of the product, by deciding the features and specifications required.

Adaptive customization: In this case the customer doesn´t decide the features or full specifications, but still has possibility to customize the product. A good example of this kind of customization can be a chair, where the inclination or height can be regulated, thus fulfilling different customers' needs accordingly.

Cosmetic customization: The customization is not in the product itself, but in the marketing, or how the product is differently presented to different customers.

Transparent customization: Consists on providing individual and unique customized products, but without the customers stating their actual needs (because they cannot state their real needs with a configurator, or because they don't even know that the product is customized for them)

Postponement is also an important topic in mass customization, because is one of used tools to give a customized experience, while using some of the advantages of the mass production.

In the next figure, it can be seen how postponement is used from make to forecast up to engineering to order in production plans [10].

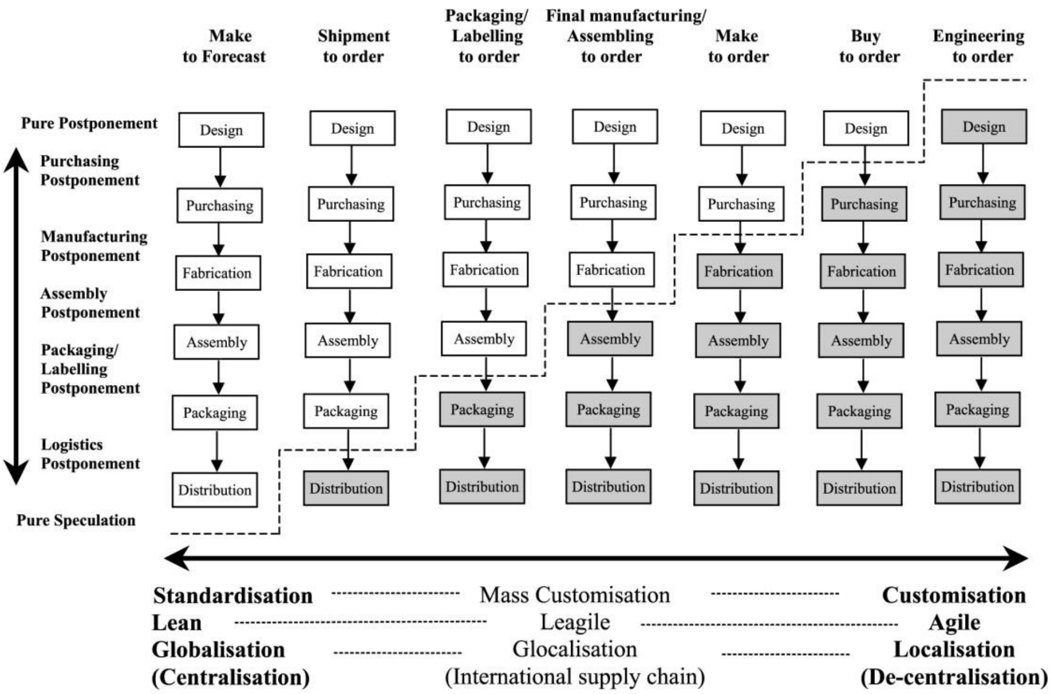

Figure 14: Postponement levels in the supply chain [11]

As it can be seen, mass customization lies between the standardization and customization, mass customization can be defined as "*a process through which companies can* *provide customized products or services, through flexible processes in high volumes and at reasonably low costs*" [12].

To offer a customized product, while being able to have reduced idle times and competitive prices, a part of standardization is needed. Family products, with similar specifications, or standardized parts are very used methods to stay competitive and improve cost and reduce the times, while offering a customized product that will fill the needs of the customer.

When more postponement in the supply chain happens until the product is customized; more standardization and lean strategies will be implied. In the other hand, the earlier the product will be customized in the supply chain the closer to pure customization (Engineering to order) in those cases agile approaches will be used

The postponement (which means that some of the steps in the supply chain will be standard) is what makes possible to offer customized solutions with a competitive price. The point where this happens is called the Order decoupling point [11].

For an appropriate mass customization level, some known principles are usually applied [7]:

- *Modularization of products, process and teams*
- *Applying postponement*
- *Applying the principles of flexibility manufacturing and lead time reduction*
- *Extend cost effective principles throughout supply chain*
- *Apply DFMC (Design For Mass Customization) principle in the product development phase*
- *Customer integration (CRM) and market study*
- *Establishing sophisticated information systems*

Using DFMC means, designing the product to be mass customization-ready, to do so family products, and similar components should be used, another key process is the modularity, shared modules for different products to help having standardized parts, it will help merging the mass production and the customization, in order to obtain customized products at competitive prices.

When adding the design as an enabler for MC (mass customization), 4 different key enablers for the different categories are found [13]:

In design the modularization, products family, shared components and process commonality help in enabling the MC, Design For Mass Customization (DFMC) aims at considering economies of scope and scale at early stages of the product design. [8].

In manufacturing, advanced manufacturing technologies such as FMS (Flexible manufacturing systems) help in obtaining the needed flexibility. FMS are composed by two parts: The physical, where the needed automation technologies are present hereby adapting to different needs, often robots are used due to their flexibility, the other part is the control part, which determines how the physical part should perform the tasks for each order in an organized and optimal way. Another enabler in manufacturing is the postponement as stated earlier, and process improvement in order to obtain a cost effective and error probe process.

Finally in sales and purchases, the commonly used enablers are the IT tools, such as configurators and order processors. According to a recent McKinsey survey, digital operations are a critical driver of competitiveness, at the same time, manufacturers identified a drastic need of improvement in certain applications to help them with the integration and collaboration in processes [14]. Another recent trend is the use of Software as a Service (SAAS), offering a cost effective, easily scalable and very flexible IT tools, that traditionally have been installed in-house, this represents an opportunity to adapt to the rapidly changing business environment with ease, and without big upfront investments.

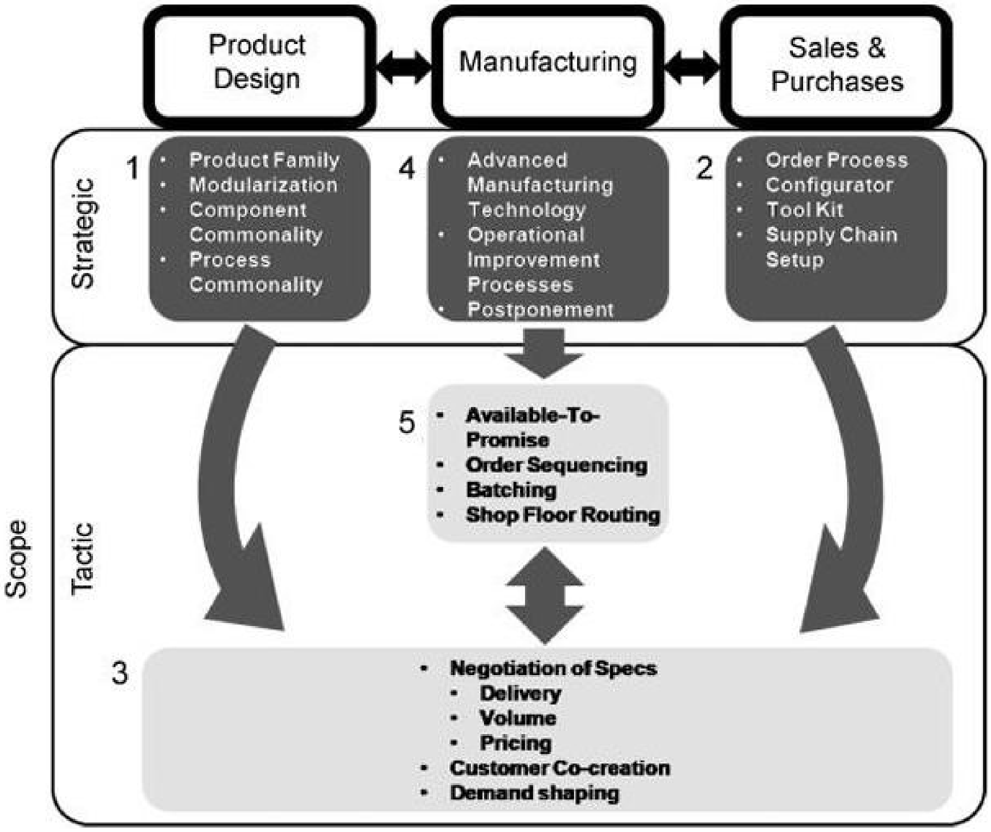

Figure 15: Proposed framework for the categorization of MC enablers. [13]

Process improvement

As three of the tasks for this master thesis involve improving the machine or the process in some way, a review of widely used methods will be done in order to provide an understanding for the methods that will be used in the development part.

Statistical quality control

As stated before, quality is one of the key characteristics for competitiveness, an example to that end could be the rise of TQM approach in the organizations.

Different tools are used by quality professionals, the set of them is described as Statistical quality control (SQC). Those tools can be divided into three categories [15]:

- Descriptive statistics: Focus on the collection, analysis, presentation and description of a set of data [16].
- Statistical process control: Involves random inspection of a sample to decide if the process is producing within predetermined range.
- Acceptance sampling: Process of deciding if a batch is going to be accepted or not depending on a random inspection of a sample good.

Descriptive statistics use a set of measures in order to analyze the input data and understand what the data shows. Some of the most used descriptive statistics are:

- The mean or average: Measures central tendency of a set of data is calculated by the sum of all the set of data and dividing it by the number of items taken in the set of data.
- Range: Is the difference between the smallest and largest value.
- Standard deviation: Measures the amount of data dispersion around the mean, is calculated as following [15]:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{1}$$

Where:

σ= Standard deviation of a sample

$\bar{x}$ = The mean

x_i= Observation i, i = 1,…,n

n= number of observations in the sample

SPC usually uses control charts, where it can be seen if the process is out of control, or how stable it is. For that purpose different types of control charts are used:

- Mean charts (x-Bar): The changes on the mean value are represented to see how they evolve.
- Range charts (R): Monitors changes in the dispersion of the process

Those measures should show that the production process is in a state of control ideally. A very used and important measure when evaluating the ability of the process is called the process capability, which represents the ability of a production process to exceed the preset specifications.

Process capability is a key figure for the six sigma quality, widely used in lean techniques, having a high process capability is a requirement in different industries.

. The process capability index (C_p) is calculated as following for a total of 6 standard deviations:

$$C_p = \frac{specification\ width}{process\ width} = \frac{USL - LSL}{6\sigma} \tag{2}$$

USL stands for Upper specification limit, and LSL stands for lower specification limit. Using process capability is enough if the process variability is centered, but if not, C_{pk} is used.

$$C_{pk} = \min\left(\frac{\text{USL}-\mu}{3\sigma}, \frac{\mu-\text{LSL}}{3\sigma}\right) \tag{3}$$

Being μ the mean of the process.

Different process capability using different standard deviation, relates to different PPM (Defective parts per million) as it can be seen in the next picture.

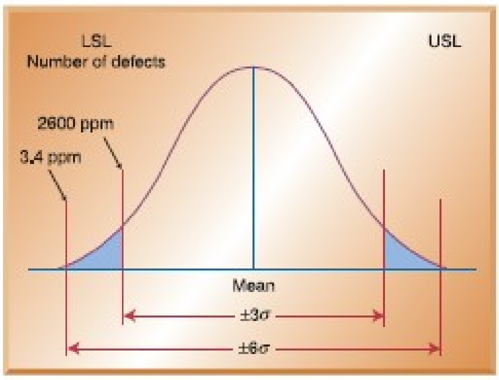

Figure 16: PPM defective for 3 or 6 sigma qualities [15]

Finally, the product specifications, also known as tolerances, express the acceptable quality measurable characteristics.

As not all the pieces can be measured, it is usual to use probability plots, to see the correlation between measures in different pieces. One of the most used distributions is the normal distribution, which is easily recognized by the bell shape as seen in Figure 16. The properties of the normal distribution are the following [16]:

- The normal distribution is bell-shaped and symmetrical in appearance
- The normal distribution measures of central tendency (mean, median and mode)
- The normal distribution probabilities are determined by two characteristics: Its mean, μ, and its standard deviation σ.
- The normal distribution has a theoretically infinite range.

To see if a set of data is following a normal distribution, normal probability plot is used, where the plot should look like a straight line meaning that is following the normal distribution, all the previously explained numbers and graphs are easily represented using specialized software such as Minitab.

Production time calculation and reduction

The manufacturing cycle time is comprised of operation cycle time and downtime (which is the sum of loading/unloading, set up and machine idle time).

The formulas for manufacturing time (per batch and work unit) are the following [17]:

$$T_B = T_{SU} + T_{ID} + Q_i \cdot (T_{LU} + T_O) \quad (4)$$

Where:

T_B: Batch processing time

T_{SU}: Set up time

T_{ID}: Machine idle time-> Major reasons include starvation or blocking of parts and worker unavailability.

Q_i: Quantity of i-th batch

T_{LU}: Loading/unloading time per work unit -> Required for the initialization and release of machine operation.

T_O: Operation time per work unit

$$T_P = {T_B}/{Q_i} = {(T_{SU} + T_{ID})}/{Q_i} + T_{LU} + T_O \quad (5)$$

Where:

T_P: Average manufacturing cycle time per work unit

OCT: Operation cycle time (T_O)

DCT: Downtime (time where machine is not working equals = ${(T_{SU} + T_{ID})}/{Q_i} + T_{LU}$

Cycle time per work unit is the sum of the operation cycle time (OCT) and the downtime (DCT), as it can be seen extracted from equation (5).

OCT is usually defined by the machine and is difficult to change unless costly changes are made. Another way to reduce the production time per piece is to reduce the DCT, to do so different times can be adjusted, or batch size could be changed, but this is not useful as batch size is determined by due date and priority [17]. So other ways to improve the total time per work unit are to reduce the loading/unloading time, the set up time or the idle time.

To reduce the loading/unloading time, process could be automatized, or special tools designed to help the workers in the process.

For reducing the set up time, different methods can be used, such as Single-Minute Exchange of Die (SMED). Firstly all the task, components and tools involved in the set up are identified. Secondly the internal and external operations are distinguished. Then, all internal operations that could be turned into external are converted, thus helping to have as much as possible prepared for when the machine is stop. Finally the unnecessary operations should be eliminated, and optimization should be done (starting by internal operations and following by external).

Part of the idle time, is produced by human factors which might not easy to control by the management, but other part of the idle time is produced because the processes are not correctly balanced, it is necessary to consider logical order of tasks and the time required for each one [4]. In the case of flexible manufacturing is more difficult, as each new batch will require different operations and different times, thus in one batch, the workers might have a low workload, and a higher one in other cases. But as in the cases when CNC machining is done, the worker has to be waiting until the machine processes the piece, this time being bigger than the loading/unloading time, the worker is not adding value for a considerable amount of time. Because of that, Shared Worker Environment (SWE) exists.

As efficient labor use is an important factor of competitiveness, some companies are using one worker to operate different machines during the idle time of workers [17]. The idea is to use the waiting time when the cell is machining to load/unload the pieces in another machine. By doing this, the production rate can be increased with the same amount of labor.

Lean thinking

There are five main principles for Lean thinking [18]:

Specify Value: Value is defined by the customer, so it is critical to have a good understanding of what is what customer really needs.

Identify the value stream: Consists on eliminating Wastes and minimizing the necessary activities. Waste could be defined as any activity that even using resources doesn't create value. Strategy should be to eliminate non-value adding tasks and minimizing necessary but non-value adding tasks. There are 7 main sources of waste defined [19]:

- Over-production: Making more than the needed amount required by customer, to make it earlier than needed or to make it just in case.
- Waiting time: Any delay between steps, which affect negatively to the flow of production.
- Transport: Movement of materials or information which is not required.
- Over-processing: Adding more value than the customer is asking for.
- Inventory: Excess inventory between operations (WIP) or excess final stock.

- Motion: Unnecessary movement of workers or machine which is not necessary for production.
- Defectives: Product defects rework or service defects. A defect may involve throwing the piece and doing a new one, or wasting resources to improve it.

Flow: After specifying the value and identifying the value stream, it should be ensured that there is a continuous flow during the supply chain.

Pull: Pull method means to produce exactly what customers' need and to have enough flexibility to cope with the changes that could happen.

Perfection: Continuous improvement is a key topic in both Lean philosophy and Total quality management. Customer expectations should be met within time and quality requirements. As Shigeo Shingo, considered the main expert in the Toyota production system, once said: "The most dangerous kind of waste is the waste we do not recognize." [20] It is really critical to know where waste is happening, because otherwise it is impossible to know where the possibilities for improvement and perfection could happen.

Development and results

During this chapter, the actual system will be described, including the problems that have been detected. The first step in the development has been to understand how the machine works and what are the errors/causes triggering the errors and low utilization, by doing different analysis, such as Statistical quality control, comparing the robot cell with the CNC machine cells and even a set of instructions for the workers.

Afterwards, once the problems start arising, and the causes of them could be detected, some changes were done in the robot cell to solve the problems, and see the real source of them. Then running the machine again to check if the problems have disappeared or not.

Mass customization in Ensto

The Product process Matrix, developed by Hayes and Wheelwright [21] shows the interaction between the product and the process life cycles. With this matrix (Figure 17) it can be seen that both Utility network (UN) and building technology (BT) business units use an assembly line type of process, while the Industrial solutions (IS) are mainly using batch production process. In the other hand, while in IS standardization is high, UN and BT don´t almost offer any customization.

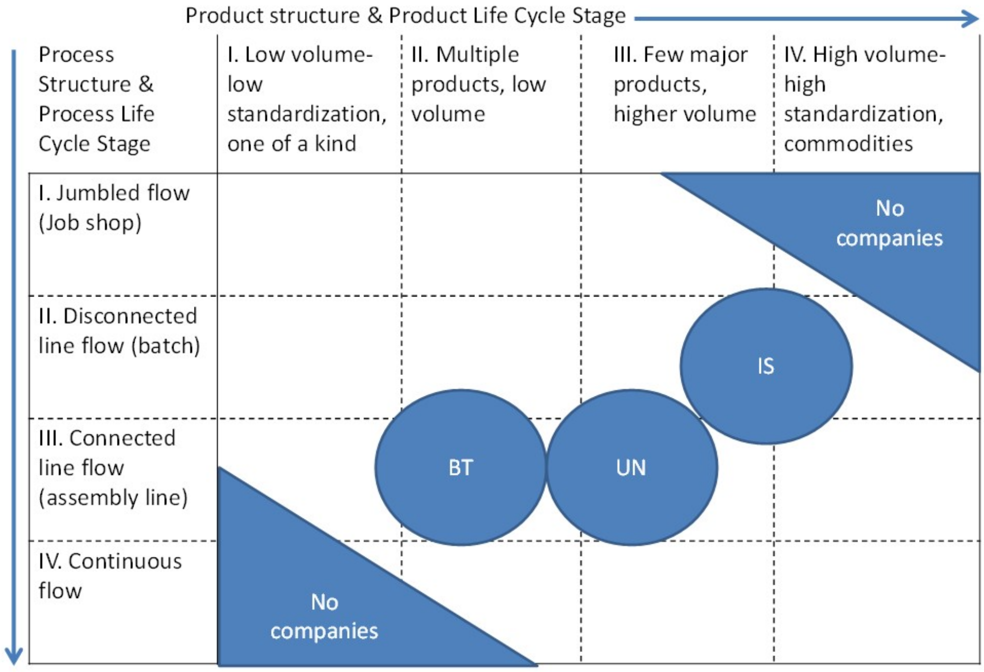

Figure 17: Product process matrix in Ensto

Because of this in 2008, a project was launch, in order to offer the needed flexibility for the IS enclosures products.

IS business is the only one offering truly customized products to their customers. This is the case of the plastic and metal enclosures. But still, the enclosure customers can buy a standardized product, and do the customization themselves (drilling holes and/or inserting needed parts inside the enclosure). Because of that, and looking at the postponement matrix, Figure 14, the different postponement used in Ensto enclosures will be explain, the offer goes from Shipment to order up to engineering to order.

In the plastic enclosures, customers can choose among one of the many products in the range. Customer can buy the product in different ways:

- Buying the standard product (Shipment to order, Logistics postponement), this process is standard and lean techniques are used in order to offer a reasonable price while maintaining a good quality.
- Buying the standard product with special packacking (Labelling to order, Packacking/Labelling postponement)

- Buying the standard product with assembled parts inside (Assembling to order, Assembly postponement), not too often as the enclosure usually requires holes.
- Customized enclosure (Make to order, Manufacturing postponement), with plastic enclosures the enclosure is done as a standard one, but then different holes or openings are done in the enclosure to fulfill the needs. Customers then can also choose if they want some special assembly.
- Engineering to order (Engineering to order, Pure postponement), after customer chooses his own measures for enclosure (only available in metal enclosures), the enclosure is fabricated individually and for that specific customer, then the customer can also choose the assembly features. Resulting in long lead times and higher prices than having a standard product and machining it later.

To give an overview a fast calculation of possible offering permutations has been done using the online configurator. By taking the different options that can be chosen, and multiplying them

Table 1: Options available in Cubolink

Types of series	3
Different enclosures sizes	37
Different depth sizes	3
Different material	2
Different cover	2
Different opening	2
Sides to be machined	5
Types of holes	35
Different plates and rails	11
Different components	95
TOTAL OPTIONS	**487.179.000**

Almost 500.000.000 possibilities for plastic enclosures (without taking into account that each opening or hole can have multiple measures and that can be located in different places)

This offering requires a mass customization system, so as part of the company strategy of offering a mass customization service Cuboflex partnership concept was started in 2008.

Cubolink partnership consists of Cubolink (software offering the elicitation and Logistics) and Cuboflex (robot cell providing the process flexibility)

Cubolink is an online configurator, where the customer can choose his own specifications and requirements, ask for the quotes and manage the orders and finally export the 3D design to a XML or CNC file to be used in the machining machines. The solution uses various numbers of ERP based backbone tools that are integrated together, by using mainly web services.

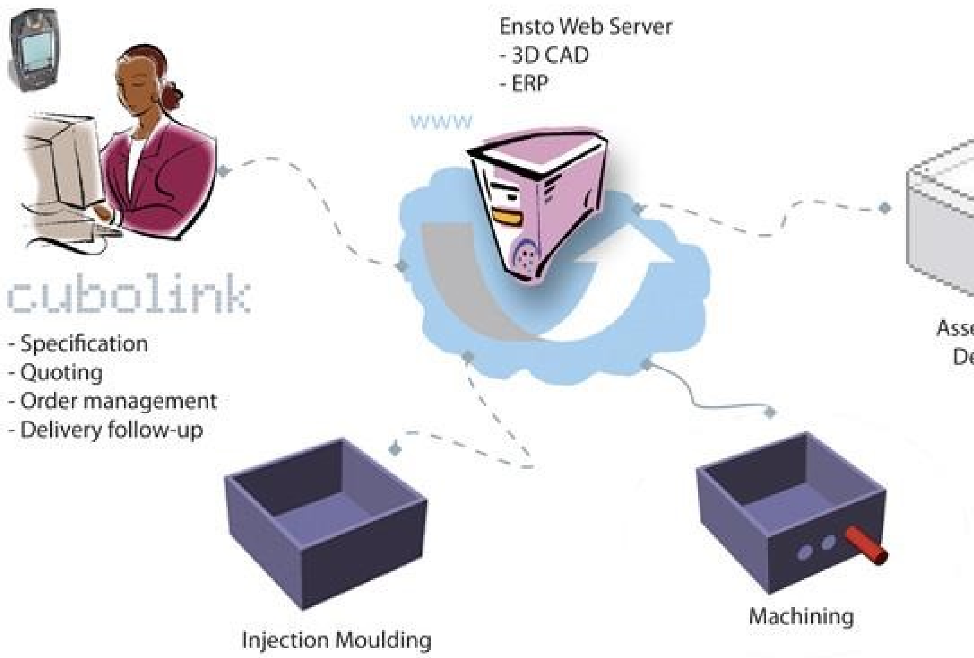

Figure 18: Cubolink concept for thermoplastic enclosures

With Cubolink the customer can customize the enclosure with requirements of different holes and openings and/or special metal enclosure measures, or different components in the web-app and when finished, order will be processed by Ensto web server, and the quotation and all needed documentation will be created within minutes.

Production and planning engineers have the possibility to put the machining file in the machining cells, from where the file can be loaded, thus not having to manually create a program when a new order arrives. This reduces drastically engineering resources as well as set-up times (especially in the Cuboflex robot cell, where the adaptive jig design, adapts to different measures of enclosures, not having to change the clamping system every time a new batch is used as it happens with the CNC machining cells).

This flexible robot cell was designed, aiming to obtain a cell where after receiving the program, is loaded to the robot, pieces are located in the belt conveyor, and without set-up robot will make the batch.

This system provides big flexibility, and possibility to work with small batches, that would otherwise not be so profitable. The set up time needed by traditional milling machines for such small batches, makes unprofitable to adapt to lot of small batches.

Even if this mass customization system was done years ago, the utilization of the machine is not as high as it was expected, because of apparent reasons as, machine complexity and lack of knowledge among others.

The flexible machine is not a standard product, which implies, that it is complex and that knowledge about is limited. Also available information is limited and in Finnish language, some of employees of Ensto have only the know-what, and very few with know-how (advanced skills).

Affter moving the robot cell from Finland to Tallinn plant, the know-why* (system understanding) was not properly transmitted, so this work, will be oriented to understand the know-why, thereby understanding how the utilization of the machine can be improved (by reducing actual problems, improving production time and proposing a new process workflow) at the same time some guidelines for the future generation of Mass customization systems of Ensto for being competitive in the global marketplace will be written.

The roadmap for this work has been: Getting to know the machine (how it works, problems, and limitations), Understanding the root of the problems, propose improvements, analyze machine without problems, apply lean methodology and Future lines.

Errors in the FMS

The machine itself has a log record of the problems and errors occurred, the logs files were taken from the computer of the robot cell. To do so the logs were imported to excel by using the get external data from text function with the log file of each day in a new sheet. As lots of unnecessary events are also recorded in the log, the needed ones were filtered, by applying a filter to show only the ones with the "error" or caution" text. After that, all the different errors were recorded and shown in a graph.

In this graph errors occurred from 21 of November 2014 to 8 of December have been collected and analyzed, in order to understand which are the most recurrent problems occurring in the machine and then try to understand why they happened.

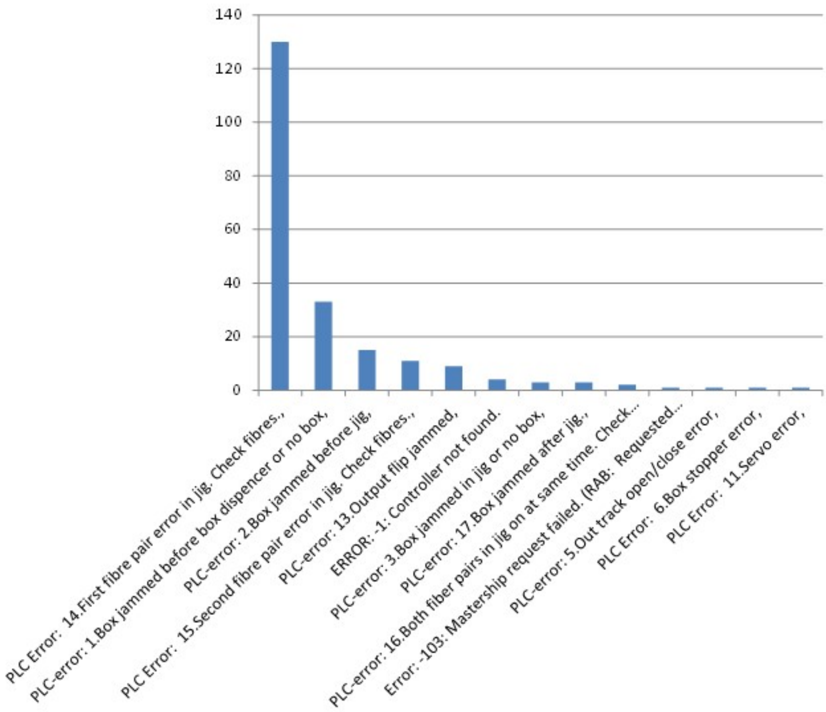

Figure 19: Errors taken from log files

Table 2: Errors by type

TOTAL	195	100,00%
Fiber related errors	143	73,33%
Jam related errors	44	22,56%
Other errors	8	4,10%

It can be seen that the main sources of problems in the machine are the fiber optic (sensors) and the jams that occur before, after or in the jig. Because of that, these two components have been more carefully analyzed:

Fiber sensors work by the through-beam principle, where a sender and a receiver are used, to send and receive the optic signal. The sender emits the infrared light; if the receiver receives the light then the light is transmitted by the fiber cables until the sensor. If any object is blocking the light and receiver doesn´t receive any light, then an output signal is activated to tell the machine that there is something in between.

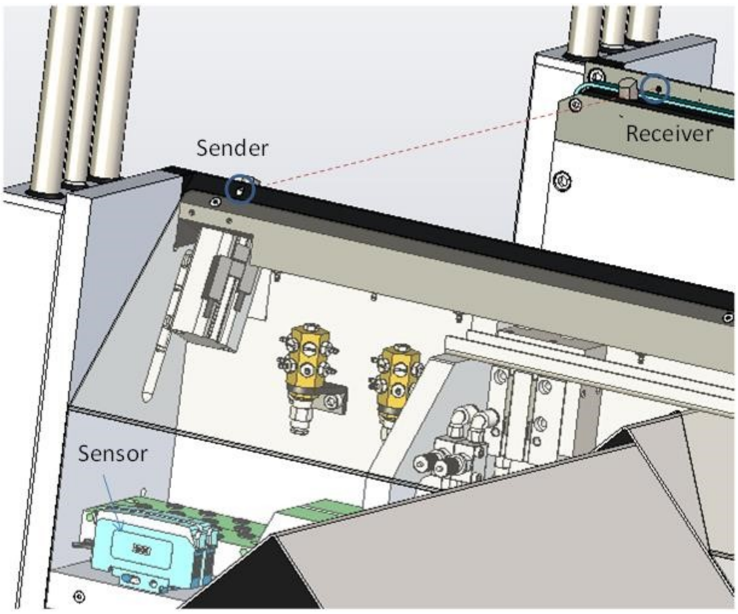

Figure 20: Situation of optic sensor

The two optic fibers are attached to the sensor, where the optic signals are evaluated. In the sensor there is a possibility to control the sensibility as well, in order to make the output more or less strict, depending on the application needed.

The main hypotheses for the errors was that plastic chips and dust would interfere with the light thus, giving a wrong lecture to the PLC and resulting in error.

After one day after trying to adjust the sender to be aligned with the receiver it got stuck, and the only option to change it was to put new ones, so all the sender and receivers were changed, and when changing them (they were never changed before), the next problem was encountered.

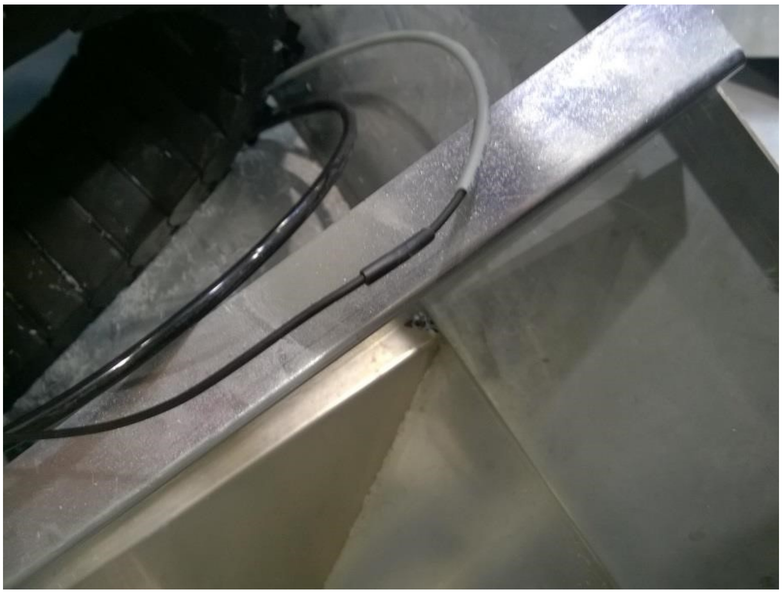

Figure 21: Fixing detail of two fiber cables

As the cable of the receiver is too short (2 meters) to directly attach it to the sensor, a simple flexible plastic tube was used to put two parts of optical cable together. As the cable is located in the movable jig part (it moves to adapt to different enclosure sizes), depending on how the cable moves, the alignment of them is lost, and that generates an error in the system, as it thinks that there is a piece in the jig, even if there is no.

The logic option is to buy a sender/receiver with larger cable, to buy an adaptor or to weld the two parts. Finally an adaptor has been ordered

Another source of errors is the loading/unloading system of the Jig, with close to 25 % or the originated errors during the analyzed period of time, jam related errors are the second cause of errors.

Figure 22: Output track for enclosures

The input and output tracks are the parts used to put the part in the jig, and to take it out when finished (see Figure 22). They both go down and up every time a piece is coming in or going out, the movement of them is obtained by an air cylinder. This generates constant impacts, and with the purpose of reducing the impacts and not making the track bounce when it goes down, shock absorbers are placed in the interior part. The shock absorbers were supposed to reduce the impacts, but as the correct maintenance hasn't been done, the vibrations of the track when it goes down it caused lot of errors in the cell.

For this reason new absorbers have been located in the tracks thus making the vibrations disappear.

Figure 23: Shock absorbers

Another critical aspect specified by the responsible of the project when it was constructed was the chip extraction; the small chips produced by the machining of the enclosures can be dangerous, producing different errors, especially when they go inside a moving part. Because of that the robot cell is equipped with a powerful dust removal filtration system, made by the Finnish company Extor. The extracted chips are removed from the robot cell and located in a container.

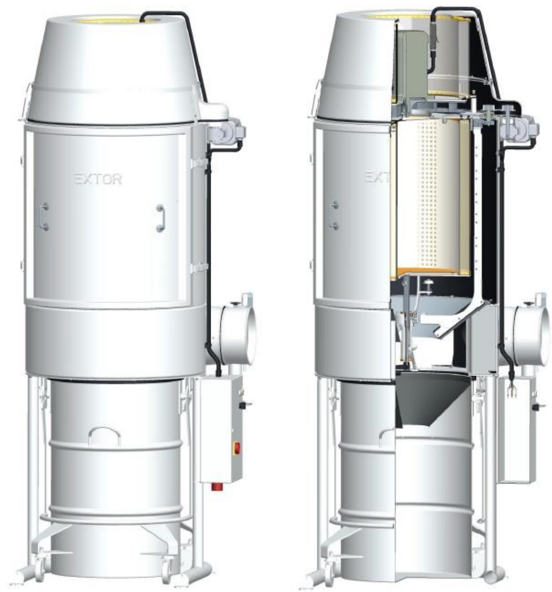

Figure 24: Dust removal system

The robot cell shouldn't have dust in the interior to prevent possible faults of the system. But when analyzing the situation, it could be seen that there was a lot of chips that they weren't suctioned by the extraction system. So in order to see the problem, the situation inside the dust removal filtration system was checked.

Figure 25: Dust removal system filters situation

The system was stuck and obstructed, both in the filter and in the pipes. An intense cleaning of the system was done. Once again, it can be seen how the lack of a maintenance schedule affects in the utilization. For that reason a maintenance schedule will be defined.

Another of the issues, that couldn´t be seen in the log is the precision of the machine, for that a study was made by making a 10 pieces batch with specific holes to see the quality of the produced enclosures, more specifically for being able to see the robot repeatability, shapes tolerances and positioning tolerances.

Statistical quality control

According to what was requested when buying the machine, the machine should be capable of providing:

- ±0,1 mm robot repeatability
- ±0,15 mm shapes tolerance
- ±0,15 mm positioning tolerance

According to the drawings the machined enclosures tolerances follows the ISO2768-m standard, part 1 defines dimensions of pieces produced by metal removal or formed from sheet metal [22], and part 2 defines dimensions of features produced by removal of material.

The tolerances shown on the drawings are the followings.

Table 3: Tolerances of enclosure machining dimensions

Nominal dimension	Accepted tolerance
>0,5 to 3 mm	±0,1
>3 to 6 mm	±0,1
>6 to 30 mm	±0,2
>30 to 120 mm	±0,3
>120 to 400 mm	±0,5
>400 to 1000 mm	±0,8

Even if most dimensions of features are between 10 and 100 mm, the tolerances of ±0,1 are difficult to achieve, when seeing what the machine is capable to offer.

As time has passed since the robot cell was purchased, and there is no instructions on calibration in order to not lose accuracy, robot should keep working within the same tolerances. A statistical quality control has been used to see what the machine is really capable to offer.

The test batch consists of 10 enclosures. With 3 rectangles in the sides B and E, and 2 in side C and D

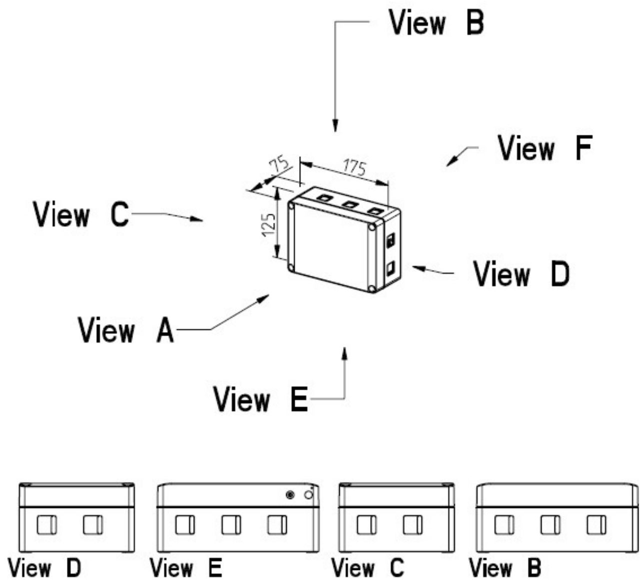

Figure 26: Template enclosure for tolerance measuring

The distances between rectangles (R_x measures) and standard deviation of operations have been analyzed to understand the repeatability of the robot. The dimensions of the squares (W_x and H_x measures) to see the tolerance of shapes, and finally the position of the rectangles have been measured starting from the same point (starting always from the zero point) to see the tolerance of positioning (Y_x and Z_x measures).

To that end a sheet has been given to 4 different workers to measure all the measures in the 10 enclosures and record them, that way the human measuring error factor is reduced as much as possible. Each piece was marked with a number for reference and the measures that should be taken, as well as the name of that dimension.

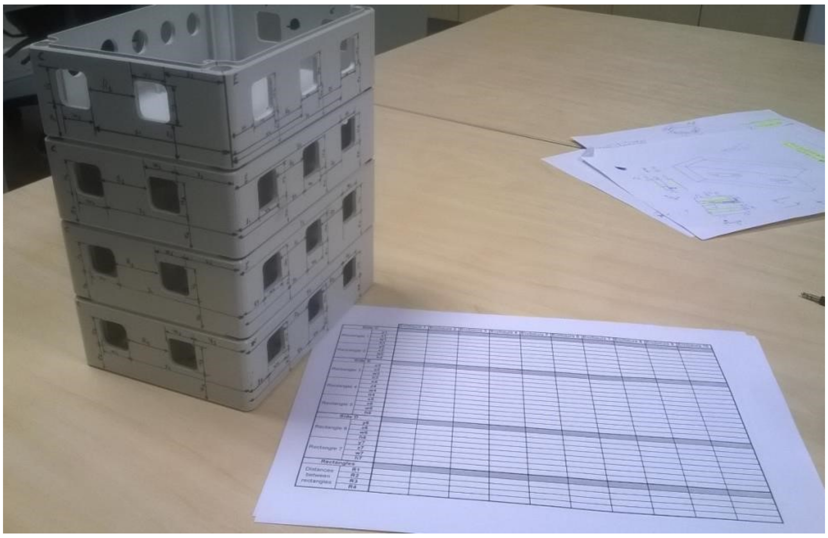

Figure 27: Template and enclosure with dimensions drawn

Once the results of measures were received from the 4 workers Statistical Process control methods has been used to see the standard deviation of the process, and also an estimate the proportion of defective parts per million, firstly using excel and then Minitab software.

The run charts will help to understand if the process is stable or not and if actual tolerances are within the specification. After the workers took all the measures, the data was inputted in a excel file, with the next results.

Table 4: Results after 1 test batch

By AXIS		MEAN	DIF	RANGE	ST DEV
C	y1	35,73925	-0,73925	0,0575	0,01704
	y2	85,7475	-0,7475	0,07	0,026588
E	y3	20,5715	-0,5715	0,055	0,017567
	y4	70,608	-0,608	0,0475	0,015626
	y5	120,5823	-0,58225	0,045	0,012273
D	y6	21,0555	-1,0555	0,0625	0,018589
	y7	71,06	-1,06	0,0575	0,021506
C	z1	19,07125	0,92875	0,045	0,016084
	z2	19,10425	0,89575	0,0625	0,02055
E	z3	18,87075	1,12925	0,0875	0,032725
	z4	18,885	1,115	0,0775	0,025631
	z5	18,982	1,018	0,045	0,017787
D	z6	18,878	1,122	0,06	0,020406
	z7	18,82775	1,17225	0,0525	0,021809
C	w1	20,11025	-0,11025	0,045	0,013716
	w2	20,121	-0,121	0,0325	0,009733
E	w3	20,15725	-0,15725	0,0375	0,012497
	w4	20,16975	-0,16975	0,025	0,007768
	w5	20,153	-0,153	0,03	0,009916
D	w6	20,135	-0,135	0,0425	0,015
	w7	20,10725	-0,10725	0,04	0,01083
C	h1	20,11675	-0,11675	0,035	0,012696
	h2	20,10975	-0,10975	0,0275	0,008118
E	h3	20,10025	-0,10025	0,03	0,009679
	h4	20,10725	-0,10725	0,0375	0,011514
	h5	20,07675	-0,07675	0,0425	0,01275
D	h6	20,1015	-0,1015	0,0675	0,017958
	h7	20,09375	-0,09375	0,055	0,019481
C	R1	29,901	0,099	0,035	0,011797
E	R2	29,8845	0,1155	0,06	0,017232
	R3	29,8665	0,1335	0,09	0,024472
D	R4	29,842	0,158	0,0525	0,014898
		MAX	**1,17225**	**0,09**	**0,032725**

When looking to the standard deviation, the maximum value is 0,03272, which is smaller than 0,033 (0,1mm robot repeatibility/3 standard deviations), that represents that the system repeatability is good, and that the system is reliable within 3 standard deviations quality.

In the other hand, when seeing DIF column in Table 4, which represents the difference between the nominal measure and the mean measure of the enclosures, it can be seen that all the Y and Z measures are out of the specifications (from 0,57 to 1,17 mm). This represents a problem, as the robot cell doesn´t provide acceptable pieces.

In the other hand, the shapes tolerance is good, as it can be seen in the measures W and H (weight and height of the rectangles). So the problem in this case is the positioning tolerance.

The program gives the opportunity to change the main zero point and as the standard deviation is good, as it can be seen from the data. Problem is that the jig has moved, thus causing wrong measures. To see how changing those measures would affect in the production, new upper and lower limits were set in minitab after calculating the best possible changes that can be done in the software, in order to put the measures as close to the nominal measures as possible. Changes were: +0,7 mm in Y axis and -1mm in Z axis.

C (holes 1 and 2), E (holes 3, 4 and 5) and D (holes 6 and 7) correspond to the different sides machined as it can be seen in the figure above.

First W and H graphs have been analyzed, those measures should not be affected by the wrong positioning of the piece of the displacement of the jig, but just merely should be based in the repeatability of the robot.

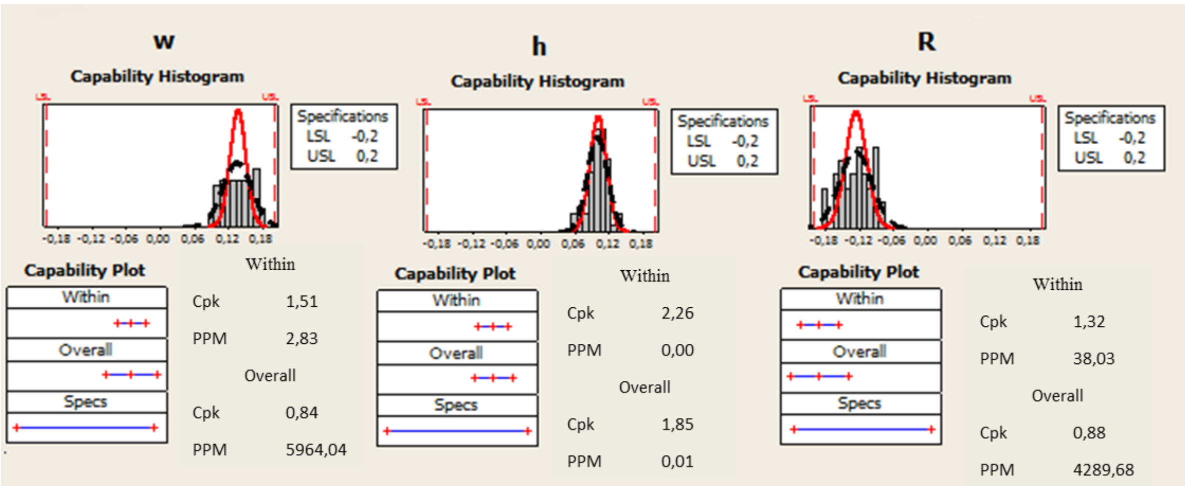

Figure 28: H (Height) and R (distance between rectangles) measures

It can be seen that the sample mean (from three sides) is around 0,1 bigger than it should be, and standard deviation is of 0,025 and 0,017 respectively. Process capability in w is 0,84 and this measure should be at least 1,33 to have a capable and reliable process.

But when seeing the results of the distance between rectangles (R) the next is found

In this case the sample mean is the opposite than in the case of W (-0,1265), the most logical reason for that might by because of the diameter of the tool is actually 0,1 bigger than it should be or because the diameter of the tool has been changed in the software, or that the macro for the rectangle operations should be improved. Still if the tool is changed and values in software are correctly defined, the process of milling should show a standard deviation of about 0,02. and a Ppk of around 2, leaving 0 PPM (parts per million) in the defective area. Thus no intensive quality control would be needed as machine will be accurate enough. Goal is to have a Ppk higher than 1,33 in all the measures of this experiment.

In the other hand, when measuring Y and Z measures differences can be seen easily, because in those cases the jig misalignment causes the measures to be not as accurate as they should be even after changing the new mean to -1 (simulating how it would change the reality when adjusting the software zero point).

Z measures show a bigger standard deviation than all the other measures.

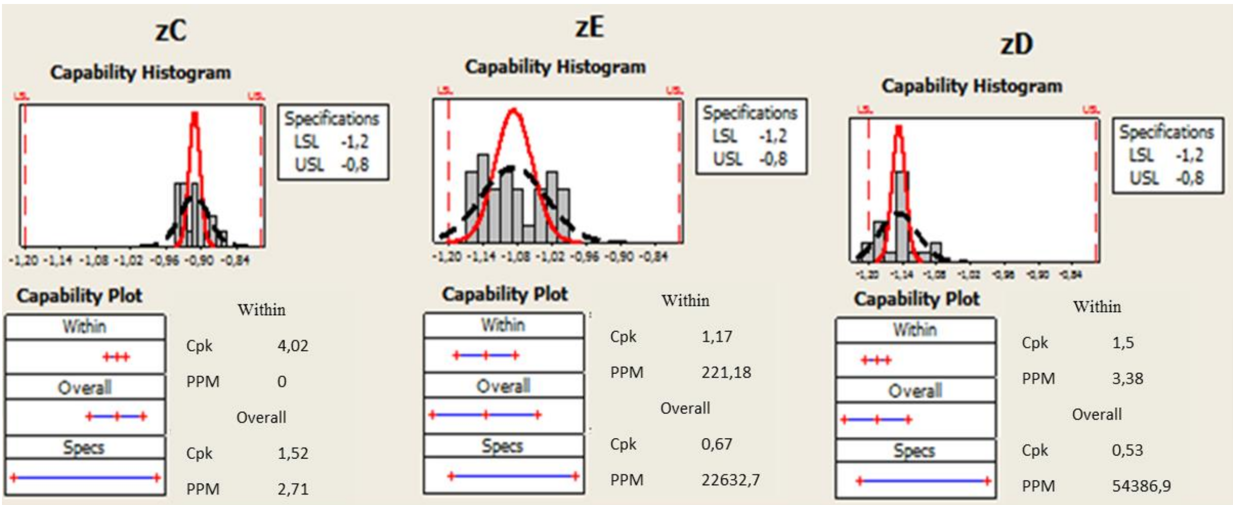

Figure 29: Different z sides measures

D side shows a 0,033 standard deviation and E is the side with the biggest st. dev. With 0,056. In this case the process capability has been analyzed, taking into account that new mean should be -1 mm and LSL and USL -1,2 and -0,8 respectively, this actually would be the same as changing the offset in 1 mm on cutcontrol to have the offset corrected.

The same has been done in Y measures but with 0,7 mm.

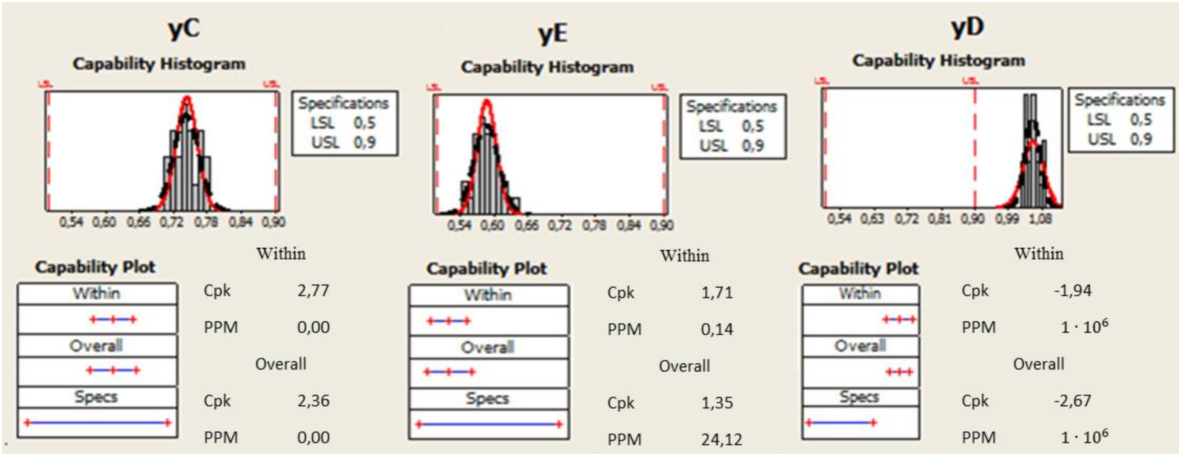

Figure 30: Different y measures

In y measures biggest standard deviation is 0,021. It can be seen that D side is out of measures in all of the cases, even if the 0,7 mm correction is done.

The results shows a clear misalignment in all of the axes, even in each side of the box, this might be due to an incorrect design of the robot cell, where adjustments are not possible to do and design is not robust enough to not bend after a long usage time.

After this first batch, and seeing that the jig was moved from the correct place, the robot was used with a dial indicator attached to the spindle, to underpin the results of the first test batch, and to see the real perpendicularity of the robot concerning jig surfaces.

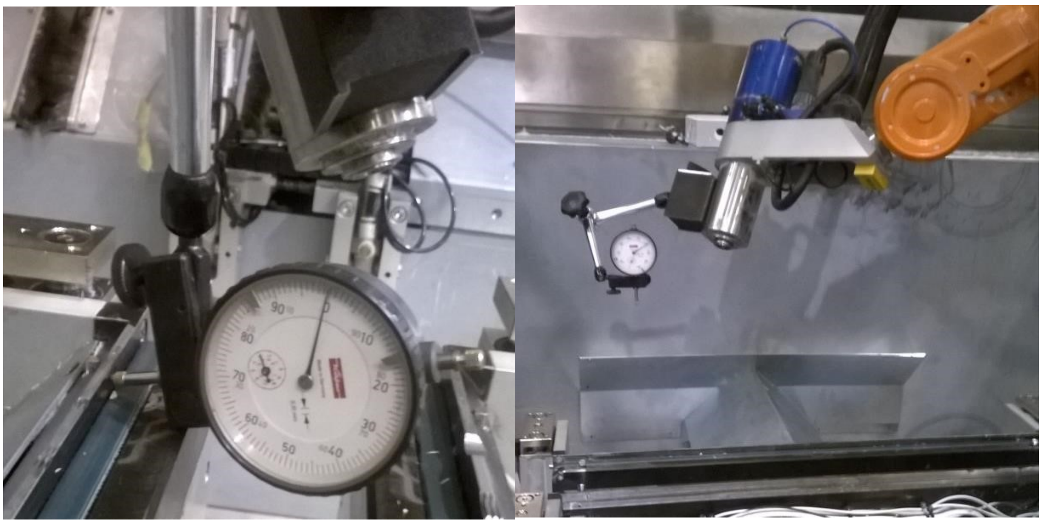

Figure 31: Dial indicator attached to robot

Each surface showed a different offset, thus pointing that almost all the components have moved during this years, probably due to an incorrect design of the jig system. The worst part of all is the end part of the jig, where the pieces go out. Because of the enclosure being fixed in one side of the jig, unequal distances on the forces creates momentum forces that bended the end part of the jig. Even if some changes were done to try to prevent it, the solution was not good enough.

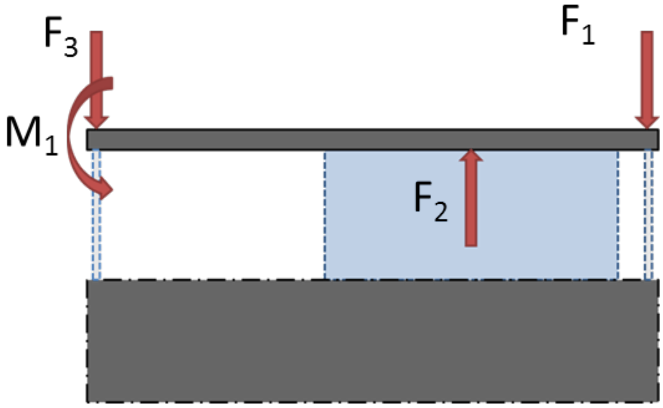

Figure 32: Representation of forces

Before doing the second test, the jig was manually adjusted after seeing how it could be properly adjusted. However, the design of the jig doesn't allow to properly adjusting the offsets, and the only bolts that give the possibility of moving the jig are the followings shown in Figure 33. And only the entire jig system can be adjusted, not each side of the jig individually. Still the whole robot cell was leveled, as well as the jig, with the available tools, without any money investment, to see how much the results could be improved. As lot of parts had to be removed, it was also the moment used to change other pieces as the absorbers and the fiber cable, also the component were checked to make sure that all were working properly.

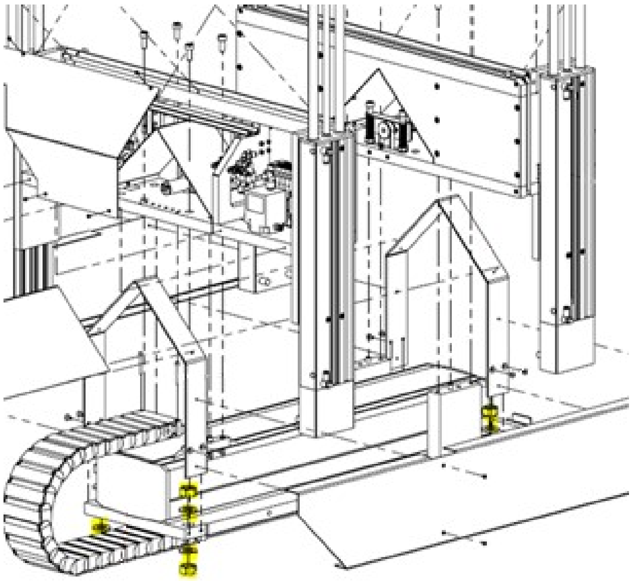

Figure 33: Bolts used for leveling

The highlighted bolts were adjusted to level the jig, while checking with the most accurate spirit level available.

Figure 34: Spirit level in the jig

Another factor contributing to the bad results of the first batch test are the Stoppers (see Figure 10), those are used for stopping the enclosure in the right position. For checking how the piece is clamped in the jig, the machine was stopped before starting to machine it to see any further problem, and following was discovered.

Figure 35: Stoppers misalignment

At first the hypothesis was that the non-rotating guide was worn, but after checking how new stoppers also rotate, it came evident that the non-rotating guide hole was bigger than the chamfered rod ending, that makes the stopper go up in different angles every time (as seen in Figure 35).

One of the possible solutions is turning the stoppers as the rounded small rotation in that case isn't relevant to the precision of the positioning of the enclosure.

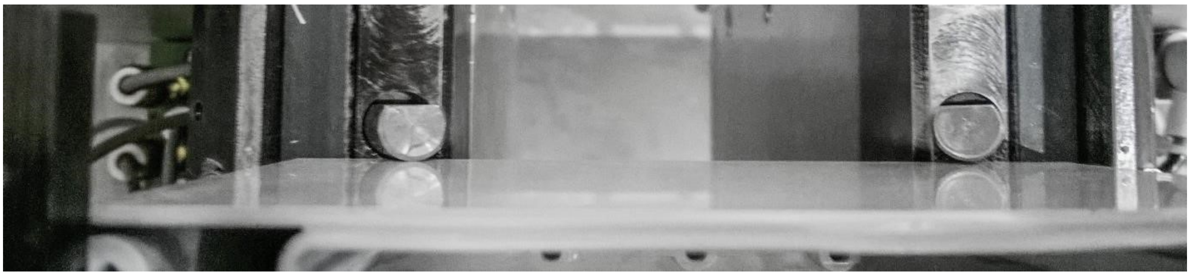

Figure 36: Turned stoppers

The problem of turning the stoppers so the round part of the rod is in contact is that offsets suffer some changes, and that there is not possibility to adjust the offsets of each side individually

After making the jig as leveled as possible, a second test batch was performed, with the following results, appropriate new zero points were set in the software also.

Table 5: Second test batch

By AXIS		AVERAGE	DIF	RANGE	ST DEV
C	y1	20,1155	-0,1155	0,16	0,042177
	y2	70,134	-0,134	0,1125	0,031429
E	y3	20,03025	-0,03025	0,2975	0,095797
	y4	70,05725	-0,05725	0,2925	0,104093
	y5	120,0625	-0,0625	0,2425	0,069242
D	y6	20,5409	-0,5409	0,244	0,095184
	y7	70,501	-0,501	0,345	0,125467
B	y8	20,16925	-0,16925	0,23	0,075582
	y9	70,109	-0,109	0,2525	0,2525
	y10	120,098	-0,098	0,2125	0,2125
C	z1	20,1445	-0,1445	0,075	0,028082
	z2	20,03	-0,03	0,125	0,044954
E	z3	19,826	0,174	0,1475	0,043256
	z4	19,7235	0,2765	0,1625	0,051102
	z5	19,7275	0,2725	0,2	0,067123
D	z6	18,6955	1,3045	0,18	0,063298
	z7	18,63725	1,36275	0,19	0,057897
B	z8	20,0225	-0,0225	0,1275	0,042377
	z9	20,00525	-0,00525	0,145	0,043276
	z10	20,124	-0,124	0,0925	0,026013
C	w1	20,12375	-0,12375	0,0525	0,016843
	w2	20,115	-0,115	0,0975	0,024944
E	w3	20,179	-0,179	0,0625	0,019083
	w4	20,20325	-0,20325	0,0525	0,018561
	w5	20,14975	-0,14975	0,0475	0,017656
D	w6	20,058	-0,058	0,045	0,012236
	w7	20,0235	-0,0235	0,065	0,022211
B	w8	20,067	-0,067	0,0775	0,024994
	w9	20,06175	-0,06175	0,0825	0,020718
	w10	20,06725	-0,06725	0,1175	0,033467
C	h1	20,0595	-0,0595	0,1025	0,028255
	h2	20,0605	-0,0605	0,1125	0,03541
E	h3	19,99525	0,00475	0,06	0,020631
	h4	19,992	0,008	0,1225	0,039119
	h5	19,98575	0,01425	0,0675	0,021732
D	h6	20,00475	-0,00475	0,1175	0,038124
	h7	20,007	-0,007	0,0975	0,026188
B	h8	19,99425	0,00575	0,11	0,030891
	h9	19,994	0,006	0,07	0,02313
	h10	19,9835	0,0165	0,1175	0,031539
C	R1	29,85275	0,14725	0,07	0,022125
E	R2	29,856	0,144	0,09	0,033875
	R3	29,88125	0,11875	0,06	0,018792
D	R4	29,94875	0,05125	0,085	0,03019
B	R5	29,93	0,07	0,1	0,026431
	R6	29,97475	0,02525	0,0675	0,018501
		MAX	**1,36275**	**0,345**	**0,2525**

Tolerance results are better now, but still the D side of the enclosure is out of range. Due to the momentum created that made the jig bended in the end part as explained before, see in Figure 32.

To fix this, different solutions were discussed:

- Change jig design: This solution is the most ideal, but as a drawback it will potentially require a high investment, and lot of time.
- Change robot program: Short-middle term solution, possibility to change the zero point of each side to machine individually, that way every time the jig moves, an analysis can be done to see how it should be changed, software developer should improve the program to include this possibility.
- Change tolerance requirements: At the moment every piece designed in Cubolink, uses the ISO2768m standard, which is commonly used for metal removal. This might be too much for the customers, and if customer real needs of acceptable specification needs can be understood this problem can be partially solved.

After talking with the quality manager the expected tolerance requirements have been appointed. And while it was accepted that the actual positioning tolerances are excessive, 1 mm offset is too much. Anyway, a study was taken to plan to change the tolerances of positioning in the drawings

That will help to reduce the lead times and reworking costs, while still offering what customer needs (over-processing is a type of waste as explained in the 7 wastes).

Instead of changing the jig design that would be costly and slow to implement, the software changes have been ordered to the software developing company. In the maintenance schedule a task will be assigned to check the progression of the jig movements. This also represented the opportunity to turn the stoppers as seen in Figure 36.

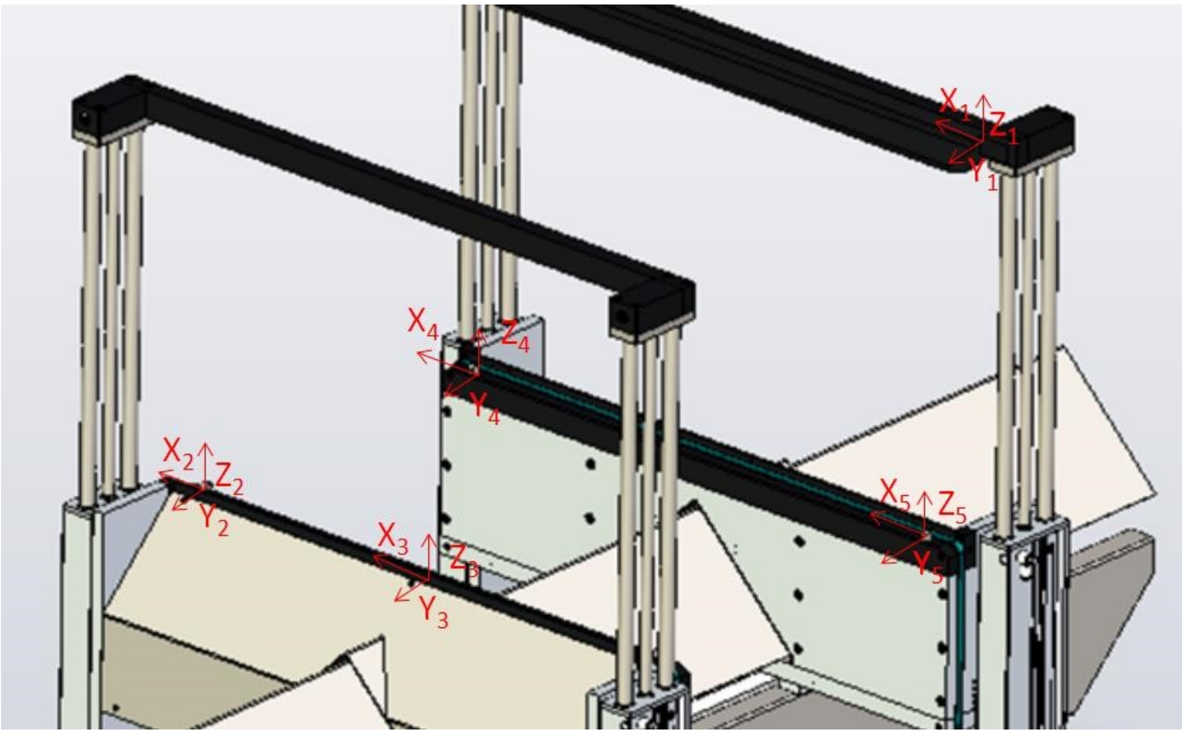

Figure 37: New zero point system

As it can be seen a different zero point is defined for the each side operations with the new software implementation, in this way, there is total control over the changes of each side, and if adjustments are correctly done, and with the low standard deviation, a quality very close to 0 PPM can be obtained. Considering the robot cell a reliable machine that will create enclosures within specifications, that way the quality checks can be reduced, and rework will be almost inexistent.

Maintenance schedule

In the robot cell manual (only available in Finnish), a few maintenance tasks are appointed: Cell cleaning, adding coolant to spindle motor when needed, greasing ball screws of the jig each six months and cleaning vacuum system once a month.

After looking at all the manufacturer recommendations and adding some new ones, especially regarding cleaning, a new maintenance schedule has been defined, the table of maintenance schedule can be found in Annex B.

This maintenance schedule should help to get rid of lot of the existing and future problems. Still when a problem occurs, it should be notified to the engineers, so they can quickly react and keep track of the failures happening.

Comparison CNC vs Cuboflex

During the introduction it has been shown that the utilization of the CNC machines is higher than the robot cell. CNC machines are standard and known machines, so the errors in those don't happen so often. After fixing the errors, understanding the failure reasons in the MT100 and proposing changes to have a reliable machine, it is time to compare both machines, and quantify the advantage of using it for small-medium batches.

The main idea is to compare the times required in both the CNC work cell and the Robot FMS cell, with the comparison, three main variables are seek

P_{idle}: % of idle time in CNC.

P_{manual}: % of required manual work in Robot cell.

$Q_{turning\ point}$: Size of batch where same time is needed in both machines.

The first two variables will be used to see if a SWE (shared worker environment) could be applied, in case $P_{idle} > P_{manual}$ happens. That will mean, that the waiting times for the workers, are higher than the required time of manual operations needed in the Cuboflex machine.

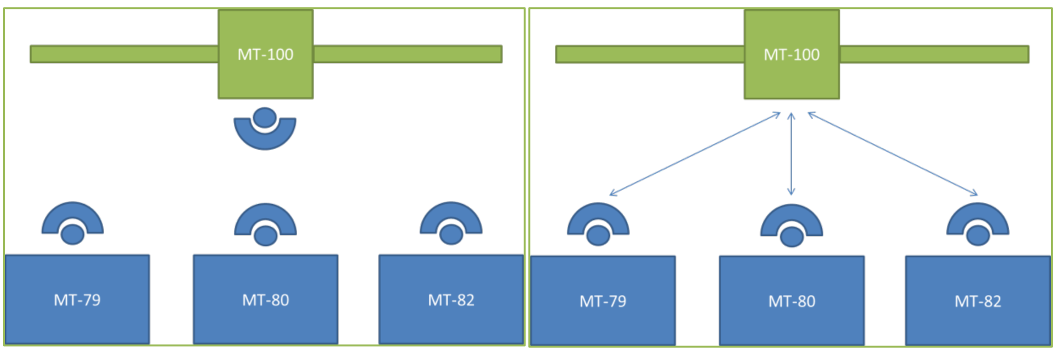

Figure 38: Non SWE (a worker in each machine) vs SWE

At the same time production time comparison will be made, to see the batch size where the turning point occurs, and is faster to use the CNC machines instead. For that purpose, the formulas on production time explained in the introduction has been used.

Time measuring of the processes helps to understand, how and where the resources are being used. For that purpose, different time management programs are existing in the market, in this case, Grindstone has been used. Task can be changed in real time, and graphics can be generated, as well as exporting the time to excel sheets.

The different processes performed by workers have been measured. Of special importance is the worker idle time, because during that time worker is not adding value. Although there should always be some idle time, in order to avoid burnout of workers

Given the technologies available in the company, formulas (4) and (5) from the existing literature and theory have been slightly changed for the calculations of needed data.

Cuboflex is meant to work with small/medium batch sizes. Because of this, the focus was to obtain an almost inexistent set up time, providing a big flexibility, but at the same time the optimization of movements and operations was not took too much into account, hence, the machine needs more time to do the same operations. The CNC, needs a considerable set up time comparing with the Cuboflex (and time is also dependent on workers availability and ability), but the time for each operation is lower, so if a graph is drawn with the total time of production of a batch (T_B) a graphic with this shape of Figure 39 can be expected. The point where two graphs interfere, called $Q_{turning\ point}$, will give an idea of when is better to plan a batch for one or the other machine, to do so different batches will be compared in both machines, to have an understanding of how different variables as sides machined, number of tools changes etc. make this number change.

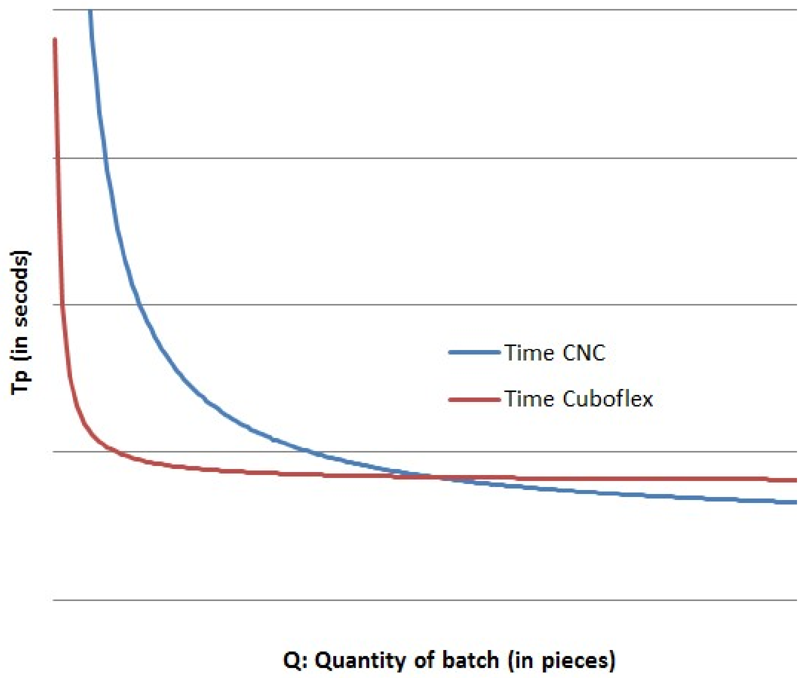

Figure 39: Production time per unit depending on batch size

The calculation of the graphs has been done by using adapted formulas from (4) and (5), because the times have been obtained by different methods.

Time measuring in CNC machines

Arrow software gives the possibility to record times, each machine has a physical box with different buttons, each number represents a state, there is a code explaining what each number represents. Once the times are recorded, the software creates graphs about information of them, as it can be seen in Figure 40.

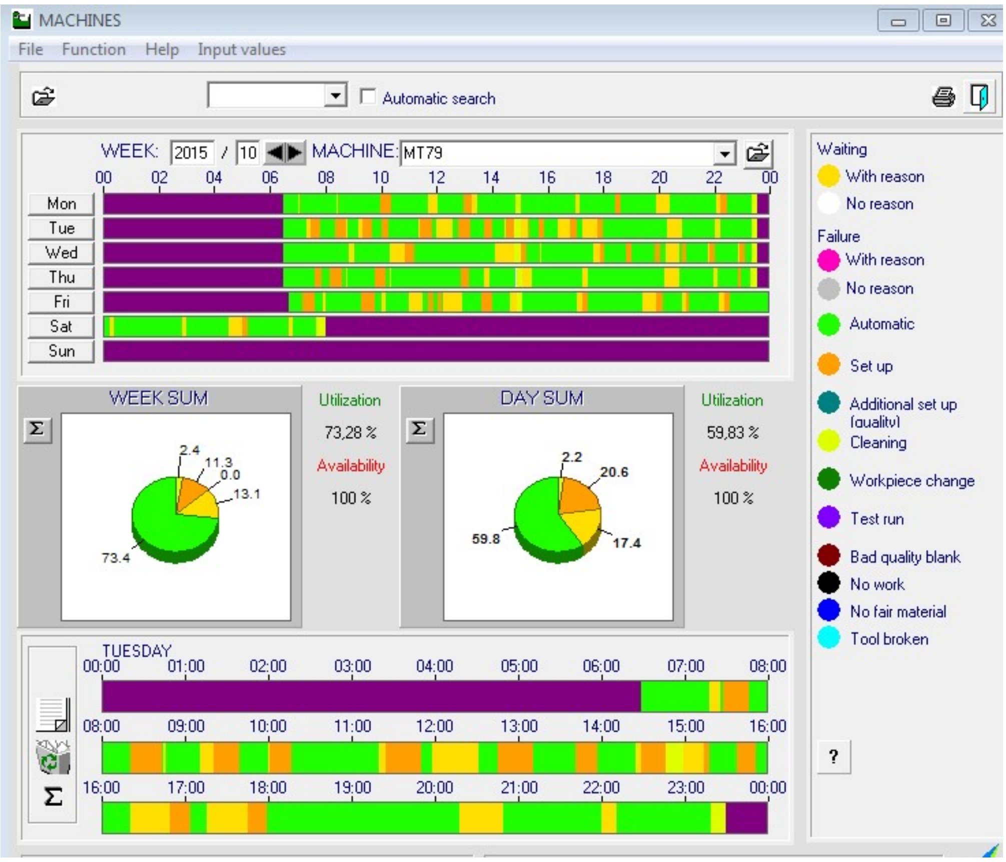

Figure 40: Arrow software

From there, information can be taken about the automatic (includes time of loading-unloading: T_{lu} and time of operation: T_o) and on the other hand, set up time will be T_{SU} and waiting time (with reason or without reason) will be T_{ID}.

So the formula for production time per piece in the CNC will be the following:

$$T_{P(CNC)} = {(T_{SU(CNC)} + T_{ID})}/{Q_i} + T_{Automatic} \qquad (6)$$

Where:

$$T_{automatic} = T_{LU} + T_O \qquad (7)$$

Calculation of P_{idle} and P_{manual}

This data is recollected manually and with the help of the software grindstone 3, where the actual task can be chosen, and graphics, percentages and even excel export can be done.

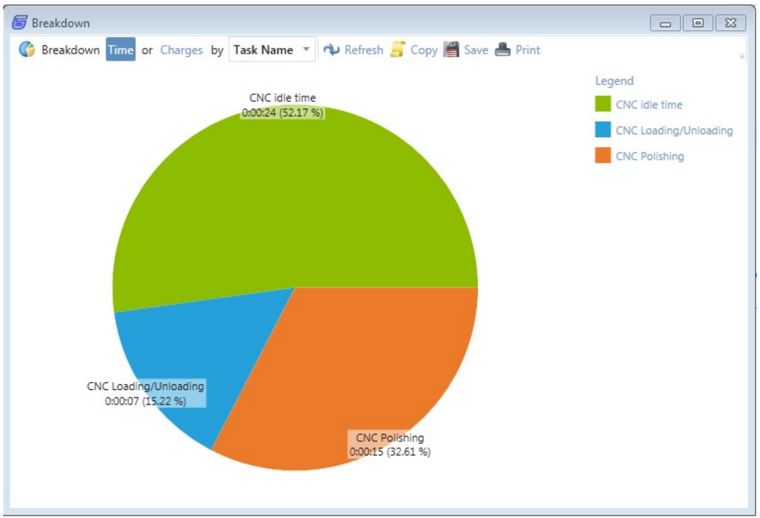

Figure 41: Grindstone time management software

In one hand, the process of the workers in the CNC machines is recorded, with usual 3 steps that are repeated during the time. Firstly unloading of the piece from the work cell when the previous piece is done, and then putting the new one in the machine and press start button. Then worker polishes the piece, by eliminating any imperfection that may arise, and random measures are also taken, to see if no deviation is occurring. Once this is done, and until the machine cycle is finished, the worker just waits (Idle time) this is the time that could be used to have a SWE, as it can be seen in

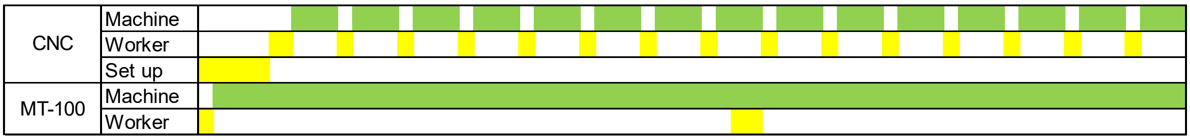

Figure 43.

For that, also with grindstone, the percentage of the time, where human interaction is required in the robot cell is recorded and the two percentages are written in a excel document, finally the percentage is multiplied by the production time per piece to see if the idle time of workers in the CNC machines is bigger than the required time for the robot cell.

Time measuring in the Robot cell

The way of getting data for the robot cell is different, the cell has its own computer, where the wanted machining program can be imported, the number of pieces wanted and more settings can be changed. In this program there is also a log, that shows the events happening, such as errors, times etc. One of them is the production time, where the time is measured, from the piece going until the piece goes out.

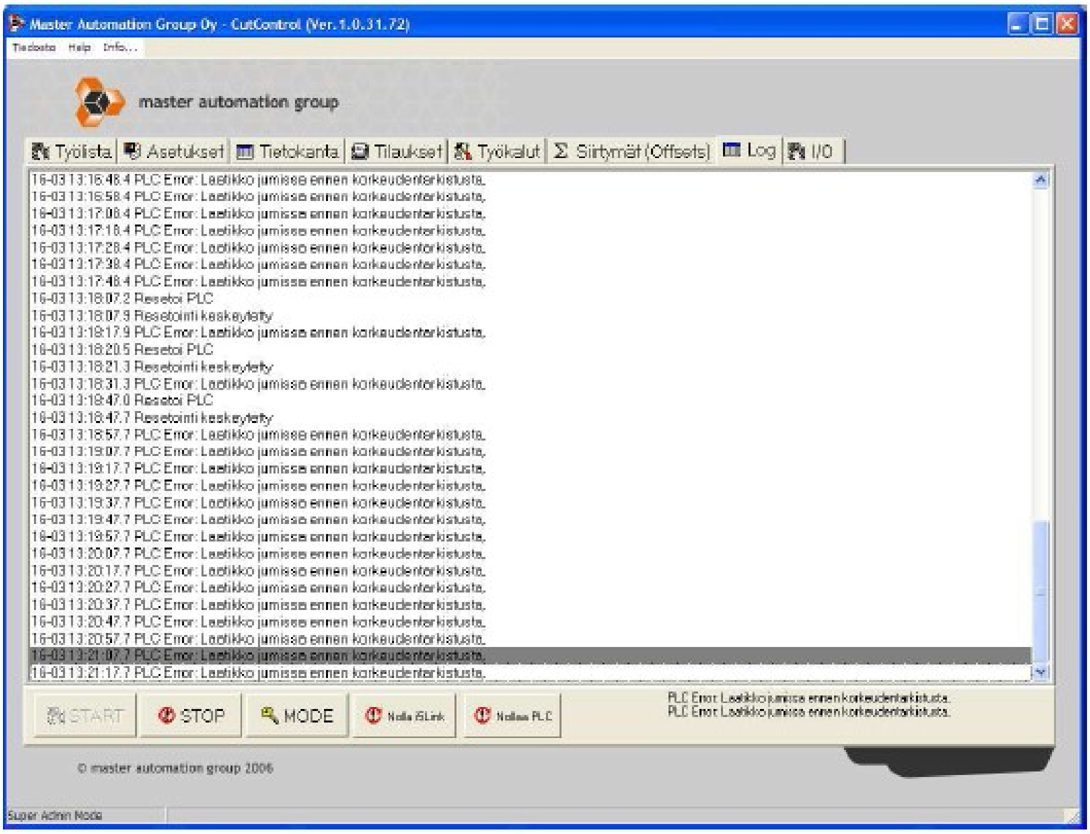

Figure 42: Cutcontrol log file

The loading/unloading of parts is also different, as the machine automatically takes the pieces from the conveyor belt, and puts it in the correct position in the jig, the time for unloading is lower than in the CNC machines, where this is needed to be done each time. This means, that the machine can be working without human interaction until no more pieces are in the conveyor belt. To do so a formula has been developed, explained in formula (11)

Anyway if some polishing operations are needed, then the human interaction is needed for each of the pieces, although as the finished pieces stay in the conveyor belt, it gives the opportunity to the worker to make this operations within a range of time, not just when the piece is finished, thereby increasing the possibility of being able to use a SWE.

So in the set-up, the time needed for loading the machining program as well as the time needed to put the maximum number of enclosures has been measured, and it will be measured with a stopwatch ($T_{SU(Cubo)}$).

In the other hand the time for loading/unloading will not be taken into account (T_{LU}=0), as this time will be done while the machine is working on other pieces, so it won't add time to the total time for the batch. In the next picture it can be seen the continuity in both machines, and when the machines needs human interaction in order to keep working.

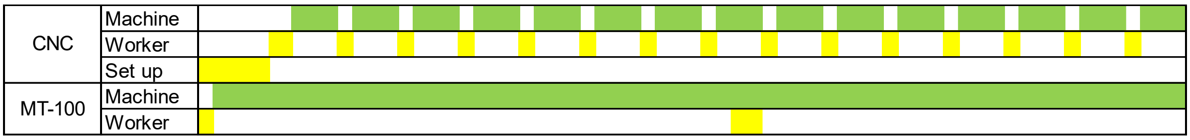

Figure 43: Worker interaction with machine in CNC and robot cell for a single batch

The machine idle time will only be considered, in case the machine shows a problem and decides to stop, because even if the workers are out of the machine, it can continue working for some time (see equation (11) for calculation). So in this case, T_{ID} (idle time) will be called T_{Errors}. So the formula used for the Cuboflex will be the following:

$$T_{P(Cubo)} = \left(T_{SU(Cubo)} + T_{Error}\right) / Q_i + T_O \tag{8}$$

In a given point of a batch, Q_i, the time for both will be the same, as it was explained previously. For that $Q_{turning\ point}$ will be calculated, by equaling the time formula per piece with both equation (5) and (7) with the same batch size, $Q_{turning\ point}$.

$$T_{P(CNC)} = T_{p(Cubo)} \tag{9}$$

By expanding the formulas following formula is obtained:

$$\left(T_{SU(CNC)} + T_{ID}\right) / Q_{turning\ point} + T_{Automatic} = \left(T_{SU(Cubo)} + T_{Error}\right) / Q_{turning\ point} + T_O$$

First, the expressions with $Q_{turning\ point}$ are moved to one side of the equation

$$\left(T_{SU(CNC)} + T_{ID}\right) / Q_{turning\ point} - \left(T_{SU(Cubo)} + T_{Error}\right) / Q_{turning\ point} = T_O - T_{Automatic}$$

Next, the batch size is written as a common divider of the two expressions

$$\frac{\left(T_{SU(CNC)} + T_{ID}\right) - \left(T_{SU(Cubo)} + T_{Error}\right)}{Q_{turning\ point}} = T_O - T_{Automatic}$$

Giving the final formula:

$$Q_{turning\ point} = \frac{\left(T_{SU(CNC)} + T_{ID}\right) - \left(T_{SU(Cubo)} + T_{Error}\right)}{T_O - T_{Automatic}} \quad (10)$$

Production planning process

An excel template has been used to see different useful parameters. For a proper comparison, 20 pieces of each batch will be done in the CNC machine and in the MT-100, afterwards recorded data for the same process in both Cuboflex and CNC will be used to compare the results. This data will help to understand: if no extra workers are needed, if one worker can work simultaneously in both machines, if the pieces are being made without error, as well as a time comparison between doing it with CNC and Cuboflex robot cell.

The following workflow has been used to complete the work

- Input product code, batch size, number of operations and tool changes
- Measure the idle time % of the CNC machine workers with Grindstone (5 times, and see percentage)
- Put Grindstone to measure the "set up time" in MT-100
- Put task operator work, when something done in the robot (only 1st measure should be counted as work)
- Check CNC production times in Arrow
- Check in the Cutcontrol log, for robot production times
- Complete the excel table

When all the needed cells are fulfilled, the following charts will be available,

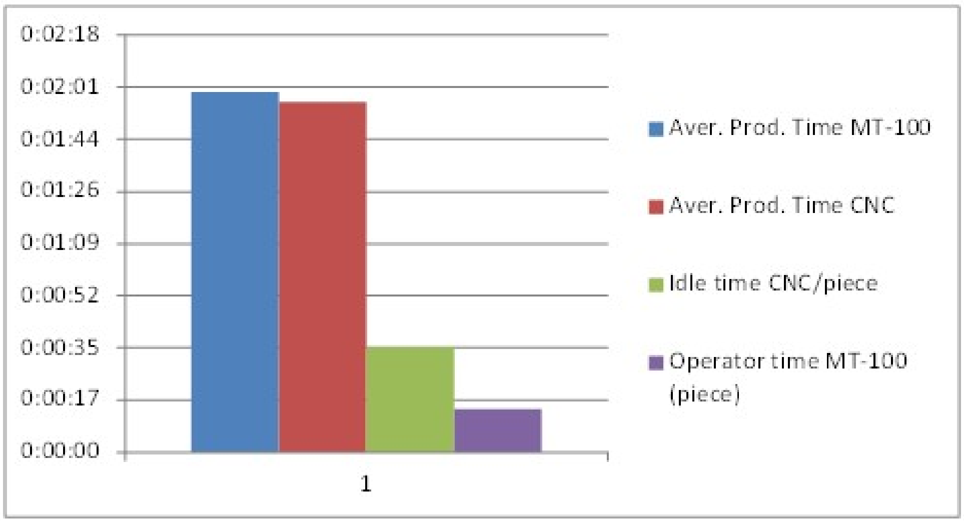

Figure 44: Comparison chart example for CNC and robot cell

The graph shows the difference between the average production time of both machines and the difference of the worker free time in the CNC machine and the required manual operator time in the MT-100. If the green bar chart is bigger than the purple one means that both works could be done with only one worker.

Another interesting chart is the one that shows the time per part needed, in function of the size of the batch

This is really important, as it will help us to understand, the magnitude of the advantages that Cuboflex can offer against the CNC machines. Further improvements could help the robot cell, to have more efficient movements and operations until getting close to the operation time of the CNC which will make the range of use for the Cuboflex wider, as an example one of the batches (2 sides of the enclosure, and 1 side of the lid machining) has been taken, and change of curve has been analyzed with different fictional % of time improvement in Cuboflex machine.

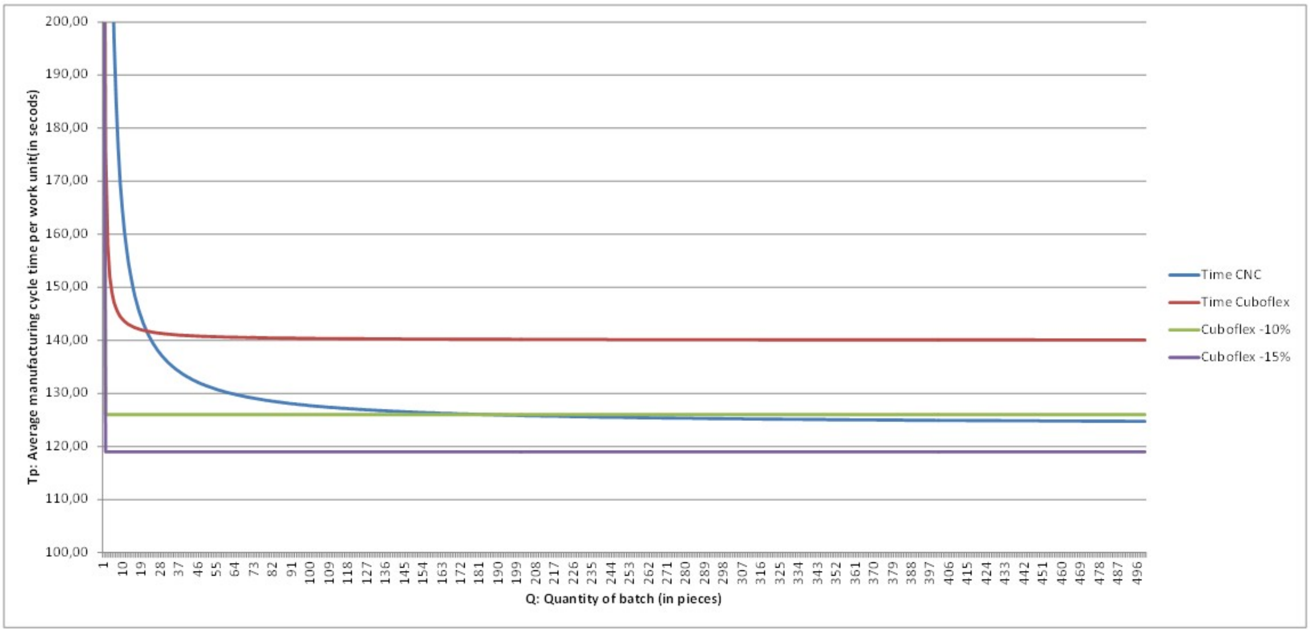

Figure 45: Manufacturing cycle times

It can be seen that if a 15% of reduction in time per machined part is done in the Cuboflex, if will be faster than the CNC for the specific case of the order KOT10714, regardless of the size of the batch.

This is for a case, where more than one side machining is done, which means that in the CNC, two different operations have to be done, with two set ups, and each piece will be loaded/unloaded twice as well, so in cases where more than one side machining is done, and with as small reduction as 15% of the time in Cuboflex, this can mean that the FMS robot cell will always be faster, regardless of the batch size.

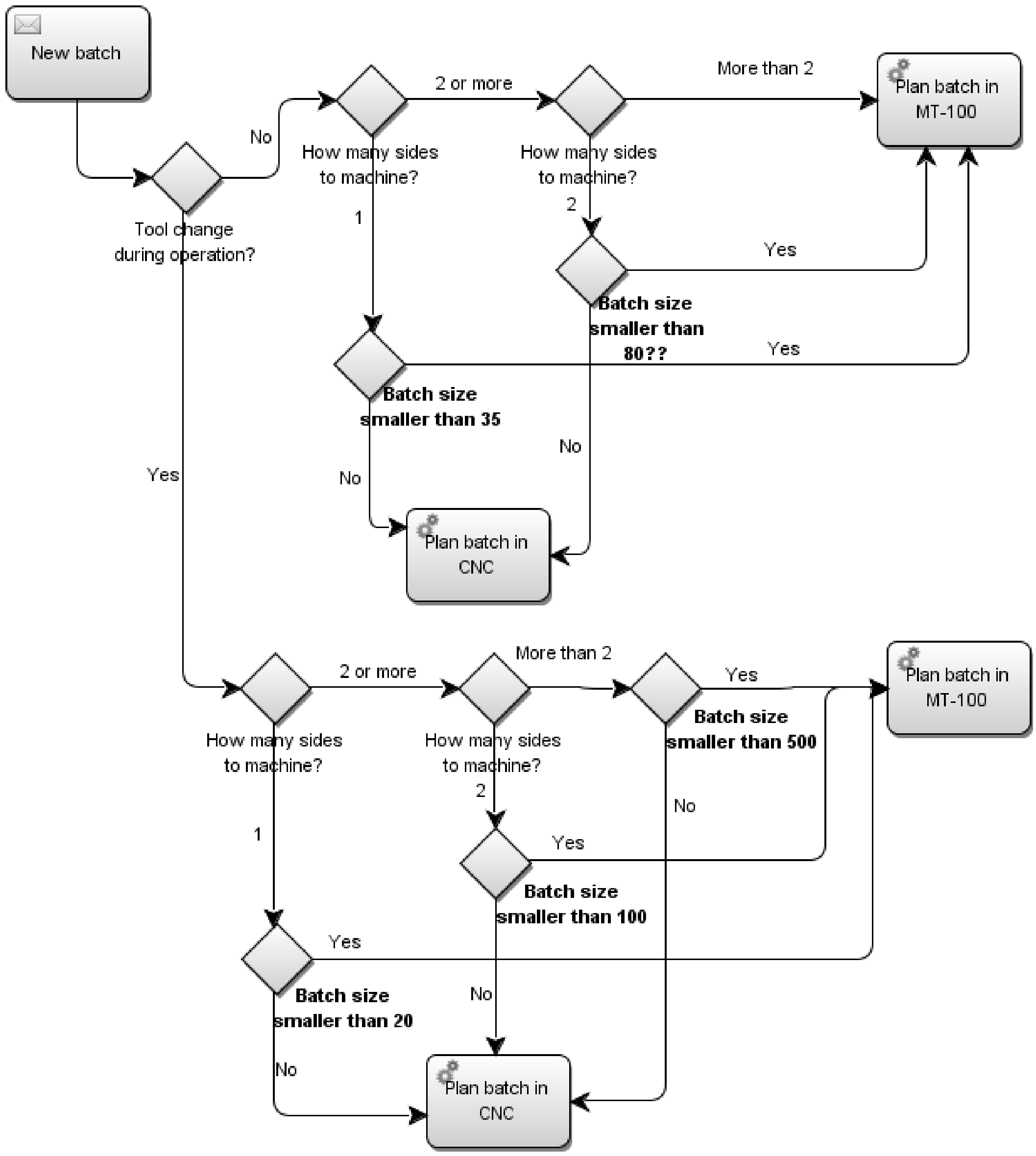

Figure 46: Production planner process to specify where to machine the batch

As production planners do not have the knowledge, of where it is better to use MT-100 a decision workflow has been designed. In this workflow, different variables for enclosure machining program are taken into account as: if there is tool change or not, and how many sides are needed to machine.

For that, different experiments, with the already presented excel template will be done, to see how this variables change the turning point, where it is faster to do it in the CNC machines, rather than in the MT-100, next experiments will be done, where calculation of $Q_{turning\ point}$ and the effect of potential improvements could be seen:

Table 6: Results of experiment 1. No tool change, 1 side machining

Turning point	35,22222
$Q_{turning\ point}$ with improvements	
% of improvement	$Q_{turning\ point}$
5	44,64789
10	60,96154
15	96,06061
20	226,4286
25	INFINITE

Table 7: Results of experiment 2. No tool change, 2 side machinig

Turning point	78,5
$Q_{turning\ point}$ with improvements	
% of improvement	$Q_{turning\ point}$
5	113,299
10	203,5185
15	999,0909
20	INFINITE

Table 8: Results of experiment 3, No tool change ,3 side machining

Turning point	INFINITE
$Q_{turning\ point}$ with improvements	
% of improvement	$Q_{turning\ point}$
5	INFINITE

Table 9: Results of experiment 4. Tool change, 1 side machining

Turning point	22,64286
$Q_{turning\ point}$ with improvements	
% of improvement	$Q_{turning\ point}$
5	27,09402
10	33,7234
15	44,64789
20	66,04167
25	126,8

Table 10: Results of experiment 5. Tool change, 2 side machining

Turning point	105,0625
$Q_{turning\ point}$ with improvements	
% of improvement	$Q_{turning\ point}$
5	186,7778
10	840,5
15	INFINITE

Table 11: Results of experiment 6. Tool change, 3 side machining or more

Turning point	533,6667
$Q_{turning\ point}$ with improvements	
% of improvement	$Q_{turning\ point}$
5	INFINITE

Shared work environment

The idea is to see the idle time for one operation and the required worker input time for the same operation in Cuboflex.

In many small and medium-sized businesses, one worker simultaneously handles multiple machines [17]. By comparing P_{idle} with P_{manual} it can be seen if the work in both machines can be done by the same person. The comparison has been made for all the experiments, taken the data from excel, as seen in Figure 44. In all the cases, the idle time of the worker in the CNC cell is bigger than the required time in the robot cell, meaning that the SWE is fully applicable and that no more workers will be need to handle the robot cell.

Applying lean philosophy

Lean is a methodology to eliminate the waste. 7 different of wastes have been already explained in the introduction section. During the analysis of the machine, some wastes have been encountered.

First one has already been explained, Overprocessing. After discussing with a manager, it has been agreed, that the actual tolerances for the average customer are too high to achieve, thus representing a waste in order to achieve a quality that is not really needed, and that customers won't pay for it.

For that reason, new tolerances will be agreed, and in case the customer needs a specific or more restrictive tolerance, then customer should specify it and pay for it, according to the value it will provide to them.

Defects are also another critical waste, and by doing the proper changes in the maintenance schedule, and software changes, defectives parts produced by the MT100 are expected to disappear.

Another spotted type of waste are the waiting times.

Table 12: Example of waiting times during a batch

	Start time	Final time	Waiting	Causes
Error 1	7:42:52	7:56:59	0:14:07	Machine stopped
Error 2	9:24:05	9:28:08	0:04:03	No box in queue
Error 3	11:48:39	11:52:39	0:04:00	Stopped by operator
Error 4	15:12:06	15:33:49	0:21:43	No box in queue
Error 5	16:52:44	17:07:45	0:15:01	Out track open/close error
Error 6	19:16:43	19:22:15	0:05:32	Stopped by operator
		Total waiting time	**1:04:26**	

Table 12, shows the waiting times derived from different human or machine errors during the early stages of research in this project. It was found, that the workers were slow to react to the different errors of the machine, or weren't able to recognize when it was needed to put more boxes in the conveyor. Because of this, the robot cell that is intended to work semi automatically, should work without human interaction for as long as possible (only to put more pieces, or take them out when finished and to start a new batch). A formula has been defined for the calculation of the maximum time that worker can be without interacting with the machine, after putting as much enclosures as possible in the input conveyor

$$t_a = t_{pp} \cdot (\frac{L_i - L_b}{Le} - 1) \tag{11}$$

Where:

t_a: Maximum time machine will be working automatically

t_{pp}: Production time per piece

L_i: Conveyor length (4900 mm)

L_b: Distance that conveyor goes back (900 mm)

L_e: Length of the enclosure

When a new batch is loaded, the maximum number of possible enclosures should be loaded so the machine can be working automatically for the longest time possible. To help the workers in this process, some visual guidelines have been included in the conveyor, with a red tape, where there should not be enclosures for a proper functioning of the conveyor. Enclosures should be only located in the white-red stripes area.

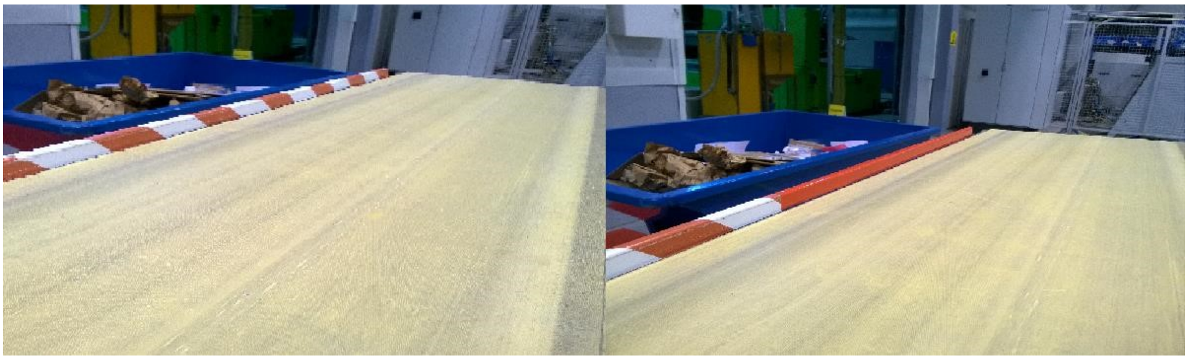

Figure 47: Limits for enclosure disposition (before picture in the left, after picture in the right

Even if some beacon exists to show the status of the machine at the moment, it is not intrusive enough, because it is out of the visual reach of the workers, thereby obstructing the immediate recognition of problems or errors. For a proper SWE, a system should be build, to make the workers know the moments when their input in the robot cell is needed, by an acoustic signal. With this purpose an acoustic signal system has been designed.

Acoustic signal system

A PLC (programmable logic controller) has been used as to use different sensors and beacon lights. With the help of a software with FBD logic (Function block diagram) with different timers and logic gates, has been defined that detects the next scenarios:

- Last piece of the batch is going to be produced, thereby workers should start preparing for the next batch or more pieces are needed to be located in the conveyor as batch is not finished.
- Too much pieces in the output conveyor, so they should be taken to prevent jams.
- The robot has suffered an error, so workers should immediately go to check what happened.

Every time one of those situations happens, the PLC will trigger an industrial buzzer to make workers aware of the human interaction need. The small screen of the PLC could help the workers be aware of what should be done, but a visual inspection also should be enough to see if more pieces are needed, if pieces have to be taken, or if some error has happen.

The inputs will be three proximity sensors (2 are already existing in the robot cell and a new one should be installed) and the orange and red beacon, that are turn on when an error occurs on the system. The output will be the industrial buzzer.

Before a new piece goes inside the jig, the enclosure is clamped close to the conveyor (a proximity sensor is installed there) and the conveyor goes back in order to leave a separation, so two pieces don't go inside the jig at the same time. So by using that process, another proximity sensor will be installed 80 cm away from that point. In that case if one enclosure is ready to go in, but after 12 seconds the second sensor doesn't recognize a new enclosure, the system will know that more pieces are needed or that batch is going to finish.

At the same time if a piece is for more than 12 seconds activating the proximity sensor in the output conveyor, this will mean that output conveyor is full with pieces, so once again the buzzer will be activated to let the workers know that they have to take them out so a jam doesn't occur.

Finally if the orange beacon (robot in manual mode) or red beacons (error) are active for more than 5 seconds will trigger the buzzer.

The main logic scheme for the system can be found on the Annex A, more logic blocks have been used to take the counters off, reset values, show messages, and even a key code only known by administrator and maintenance crew, to silence the machine when maintenance or test operations are done. All this has been done using Siemens LOGO! Software.

Process improvement

Some steps for process improvement have been considered already, such as a system to make the robot as autonomous as possible and some changes to make it more reliable. However a time analysis has been done to see how time reduction could be achieved. While the robot cell was designed to be working on low-medium size batches, it has been shown, that with some reduction in production time, it could be suitable for all the range of batches. This section will outline the possibilities in reduction of the manufacturing time, company should decide if it is worth to invest for this changes, or maybe consider to use this analysis to consider new goals if new FMS are ordered.

Table 13: Percentages for each step in the workflow

MT-100		
Box IN (not clamping until robot in position)	12,00	10,23%
Move side 1	3,71	3,16%
Drilling side 1	17,68	15,08%
Move side 2	2,28	1,95%
Drilling side 2	6,38	5,44%
Move side 3	1,89	1,61%
Drilling side 3	7,01	5,98%
Tool change	11,46	9,78%
move side 1	1,75	1,49%
drilling side 1	11,82	10,08%
move side 2	1,89	1,61%
drilling side 2	4,44	3,78%
move side 3	1,73	1,47%
drilling side 3	5,19	4,43%
open clamps	9,15	7,80%
Box OUT	7,94	6,77%
piston up/down	7,05	6,01%
cleaning air with robot	3,90	3,33%

In Table 13, a typical internal process distribution that have been measured different times and by using the average time, the percentage that represents each of the steps has been calculated.

The longest time is spent in drilling the pieces, and even if optimization of the movements of the robots could be done, it will be easier and more interesting to propose changes in the Box In and Box out steps. As they will not represent such big changes.

Speed of the conveyor could be increased, at the same time, if the FMS could support multitasking instead of doing all one after another, time reductions could be achieved. Most important time reduction could come from reducing the two last steps that are used to move the piston up and down to check that is correctly working and cleaning jig with robot. Those two steps could be avoided if a new system for cleaning is used, throwing air at the critical points such as the jig (instead of using the robot movement for that) and to the cylinders (that with a proper maintenance don't need to go up and down to check every time a piece is done), this could be done while the new box is already going.

This would represent almost a 10% reduction on time, and while a new system should be designed and few changes made in the PLC program it could represent having a suitable machine running almost independently also for high size batches in some of the enclosures.

Another way to reduce the unnecessary movements is to rearrange the disposition of the tools. The FMS software shows which tool is located in each of the tool rack, as well as the utilization of the different tools. After a new tool is selected, it measures the length in the displacement sensor, that is located in the center as it can be seen in Figure 11.

So after seeing the utilization of the different tools, 5 most used tools have been reorganized from most used, to less used, from closer to the displacement sensor to the most far from the displacement sensor (note that 9 and 10 are the closest ones, followed by 8 and 11 as seen in Figure 11).

Table 14: Position of tools in the tool rack

Tool	Used hours (as of 7 January)	Actual position	New position
4 mm frees	96:48:46	9	-
Mx1,5	28:58:1	2	10
3mm frees	8:23:3	1	8
PG16	6:58:26	11	-
PG21	1:3:20	10	12

Another interesting fact is that 11 out of 18 tools have been used for less than 5 minutes (9 of which have never been used), what means that the macros for some specific operations are written so the 4 mm milling tool is used, instead of using more specific tools that are available for that purpose. Program and macros should be check by the software manufacturer to see why this phenomenon is happening.

In the other hand, it has been discovered that when a piece with an only side operation is done and depending on how the customer makes the drawing the robot might be doing the operation in the side that is more far away. This happens because there is no optimization, and the robot itself, should warm the worker how to put the piece in order to use the closest side for machining.

As an approach to SMED, the transportation of the enclosures for new batches nearby the machines could be done by the workers on the warehouse. Also, the production planner, could load the files needed in a folder with each day, so the workers don't have to be searching the files in the software of the MT-100, which is more complicated because is a touch screen and the interface is not adapted. Those are some of the examples that should be used to externalize the work, and decrease even more the production times.

Configurator software

Flexible manufacturing system has been reviewed and different steps and solutions have been explained in order to have a reliable and properly working customizing robot cell.

In the other hand, and as explained in theory, a tool to achieve the elicitation is needed, which in the case of Ensto mass customization system is called Cubolink.

This configurator software is a key part for receiving orders. As in the case of the robot cell, Cubolink has not been much used either, with less than 10 percent of the orders arriving by this channel (even lower in plastic enclosures). The software has been mainly used by Ensto to customize and process the quotations arriving by other channels.

Some problems and issues affecting usage have been detected when using Cubolink:

- The reference point in side 2 (X_2), is affected by the fluctuation of the length of the enclosures, because the reference points haven´t been designed properly, thus adding difficulty to be within specification.

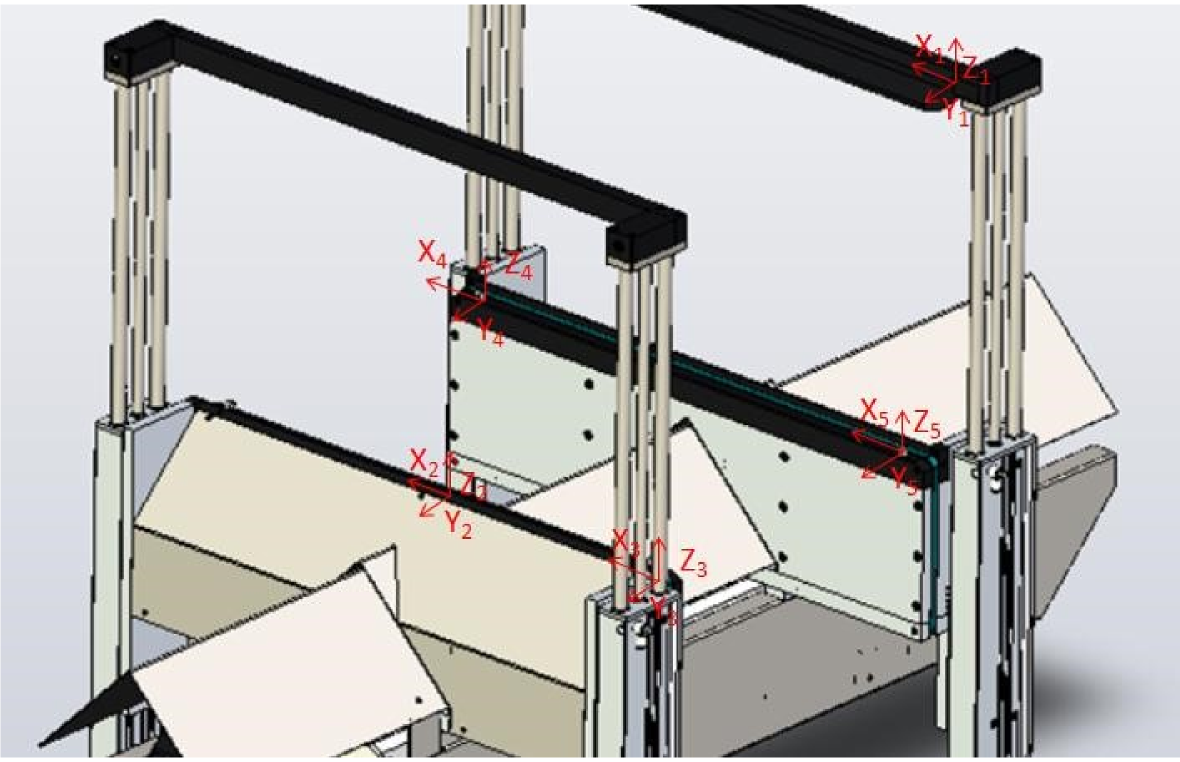

Figure 48: Reference point in side 2

- No possibility to make free shapes. Only the ones displayed in the software.
- Updating the enclosures and pieces database is slow and very costly. Due to the fact that Cubolink is custom made software, and that it has no proper integration with 3D modelling tools.
- No file management database.
- No collaboration opportunity.

Some of the actual problems could be solved by implementing a solution by an already known software maker, who makes specific software for that purpose. As an example Autodesk offers a solution, Inventor ETO.

This software can be adjusted to let the customer have more or less flexibility in the design, for example some rules can be imposed to not overcome some limits (limited by the machining equipment) or limiting the design possibilities. Also a file management system is included. So the customer can see the designs that he has already done, and made small changes to them and save as a new enclosure design for example.

There is more similar software also available in the market. But as Autodesk is widely used software in industry, it would be an already known experience for the customer.

The new configurator should be also used to personalize the system to each customer, as the customer will be used by a heterogeneous group of customer [12]. Different data can be collected such as, Customer basic info (Country, industry, size, turnover), usage of configurator (time spend in the configurator, logins without purchasing), data from invoices (occurrence of purchases, average size of purchases) and more data can be collected, to offer different start home screen to each one, or just specific sizes of enclosures depending on the industry, different prices depending on the occurrence or size of quotations. In short, the information can be used to know more about the customer behavior and adapt the customization options to each one, so their feeling of a design fitting their needs increases, leading to higher sales.

In the other hand, the collaboration possibilities helps to reduce communication steps when a special order with specific requirements that cannot be achieved in the online configurator. In that case the collaboration tool will help the customer and the technical engineer to simultaneously work until a feasible solution is met, then the salesman will provide the price for this specific special design. In that way, each step will be adding value in the supply chain.

The fact that certain software is scalable and constantly upgrading will provide a solution, which will be easily adapted to future new machines, software or different market challenges. In this regard, SAAS is actually a trend, and lets the customer easily adapt to new needs, rapidly and cost effectively. The in-promises approach for IT technologies represents high upfront investments and low adaptiveness to market changes. SAAS offers an easy solution, to pay for what you need with almost instantaneous scalability. Also the processing of the data is done in the cloud, saving time from conventional approach. A typical concern about the SAAS is the security [23], anyway SAAS is secure nowadays and more and more companies are using this approach, hybrid approaches are also possible with this technology, by mixing in-site and cloud technologies.

Finally, and as a recomendation to the company, a market research should be done to find new configurator software that can provide the next:

- Known and simple design environment
- File management
- BOM and invoice creation
- Collaboration opportunity, to reduce communication time.
- Integration with drawing standards (DXF for example)
- Export machining files to CNC and to robot coordinates.
- Possibility to show price for different configurations.
- Integration with Ensto ERP, IFS.
- User login, with personalized home screen according to his data and previous behavior.

Conclusions

The literature review was among the first steps in making the thesis, although it has been a constant process, and each article, book or journal gave more ideas and hypothesis to apply to the case of Ensto. Main topics were searched using the keywords: FMS, mass customization, utilization improvement and lean manufacturing. Plenty of the theory of configurators software has been extracted by journal articles as well as common problems in the software and factors of success, all of them with case studies. All of this has given the opportunity to give some guidelines, and to detect what could be improved.

Regarding the process capability improvement, the software changes have made possible to adjust the offset of each of the sides individually, this gives the opportunity to have access to each of the sides individually to improve the precision of the positioning.

At the same time turning the stoppers so the rounded part is in contact with the piece results in a more precise positioning of the enclosure in the jig. After those two changes a new statistical quality control was done, to set the new offset and see the results of the changes. The results results are available in Annex C. The results shows an improvement in the process capability for each of the sides, but still more improvements should be done to have a totally reliable machine, in which case additional quality control could be skipped.

At the same time the new maintenance schedule, which includes adjusting the values each 3 months (see Annex B) will prevent that new quality issues will arise. The data could be used to monitor the tendency of movement of the jig. Depending on the movement the statistical control quality should happen more often or less often.

As stated before, waste is the enemy of lean manufacturing, the different wastes affect in things like production time, customer satisfaction, lead times and a large etc. Some of the detected wastes have been analyzed and removed, as the waiting times in the MT-100 by an acoustic signal system, at the same time, unnecessary movements have been also removed by locating the most used tools close to the displacement sensor. Finally some guidelines have been given to reduce the production time even further in the future, thus providing a machine that will not give the advantage of faster manufacturing than CNC only in small-medium sized batches.

A new workflow has been also designed, the system is designed to ease an SWE, where workers will be working in their CNC machines close to the robot cell, and when the acoustic signal system triggers the alarm, the workers will note that their interaction is needed and appropriate actions will be taken, at the same time some instructions have been written for the workers in Estonian, so they can have the required knowledge to work with the machine, the system has be proven in theory and in reality successfully.

For troubleshooting, a manual has been written that will help the engineers/maintenance workers to understand where the problem is and give an optimal solution. Thus ensuring that the gained knowledge will be correctly transmited to the company staff.

Altought it is still early to provide data about the improvement in the utilization of the machine, orders have started to be planned for the MT-100 again, and will all the improvement and knowledge offered, utilization improvement should happen soon.

In the next section, some ideas and guidelines for future generations of customization systems in Ensto will be explained, as well as some work that should be continue doing to further improve the actual system.

Unsolved opportunities / Future work

After a renewal and few changes of the FMS and giving guidelines for future customization software improvent on the utilization should happen. Anyway further research and work in the mass customization system in Ensto, could imply more advantages. A few examples of those will be given.

Firstly developing a formula to estimate the production time will be helpful to help to plan the workload more efficiently. The formula would imply to take into account the number of holes, types of holes and opening etc. Because of that also a add-in could be designed for Cubolink that automatically takes the info when the piece is being done and shows the estimated time in the screen.

On the other hand and regarding to quality, axis number 2 should be located accordingly, so the difference in the lenght of the enclosures doesn't affect on quality. At the same time the reason for the differences on process capability of different axis should be studied properly.

Intelligent industrial work assistant or lightweight robots could provide an opportunity to have a system without workers, where the only thing they have to do is to locate the enclosures close to the robot cell and the loading/unloading would be made automatically. Those robots can be taught how to take the pieces and they can have intelligent vision systems to know where the next piece is in the pallet.

As stated before with a reduction in time of the production time, a system might be achieved where CNC machines can be replaced. The robot cell will serve for producing all size batches, providing a high flexibility. Such a flexible system, could be placed in all production facilities (even in partners production facilities) to reduce lead times drastically and prevent transportation costs (actually customization is only done in Tallinn for plastic parts, and in Mikkeli for metal boxes).

If the robot cell was placed in different production plants, the configurator software, could tell the customer the available enclosures in the nearest plant, so instead of choosing from the entire catalogue, customer can choose from the closest closer location if short lead time is needed for that certain project. That way customer can choose if he wants a specific enclosure from all the catalogue or it prefers to choose the best suitable close enclosure and have a shorter lead time.

Finally, a study to define new tolerances (in order to avoid over-quality) and a market study to find a new suitable configurator is recommended as stated before.

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