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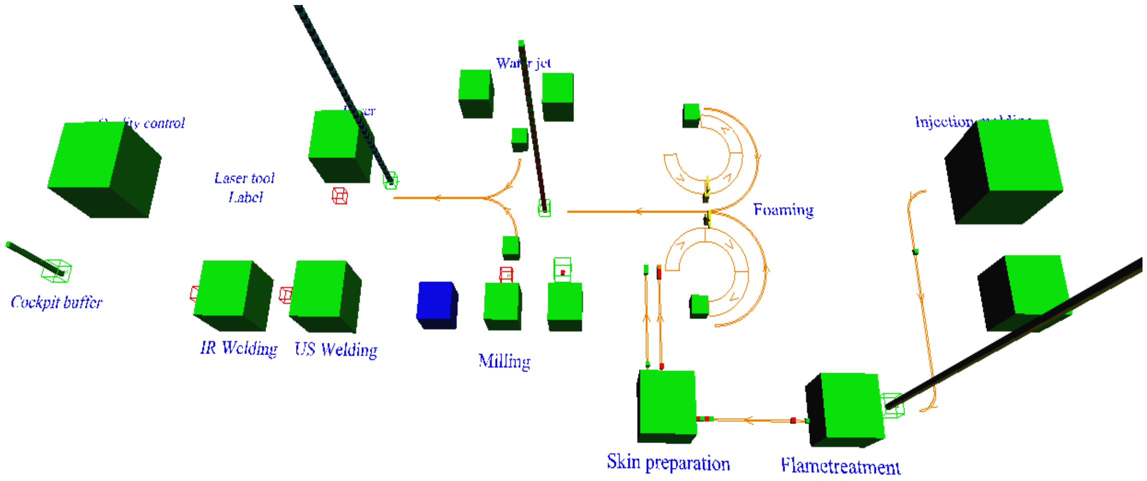

Investigation of the process flow and the operating energy consumption for a new process line

A study performed at automotive supplier IAC Group AB

Master of Science Thesis In The Master Degree Programme, Production Engineering

Ahmed Marzouk
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Preface

This report is the result of a master thesis performed during the spring of 2013 at the automotive supplier IAC group AB. The master thesis has been the final compulsory part in the master's degree programme Production Engineering provided by the department of Product and Production Development at Chalmers University of Technology.

We would like to show our appreciation to the following persons:

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- For believing in us and making this project becomes reality.

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Operators at IAC
- For answering questions during data gathering.

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Ahmed Marzouk　　Viktor Fredriksson

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Abstract

When designing a process line, it is important to ensure that the system will be able to perform according to the forecasted customer demand. In 2015, the automotive supplier IAC group will launch new products. To manage that, their existing process line has to be complemented with new equipment. The production flow will be different with the new machine setup and it is a need to verify that the system will perform as expected.

In this project, a study of IAC's new process line was done by creating a discrete event simulation (DES) model. By using this model, the process flow and the operating energy consumption were studied. Some critical questions such as; required buffer sizes between processes, required operating times for each machine and the energy consumption for the process line were analyzed. Also a brief layout review of the process line was performed. In order to analyze the critical questions, scientific theories such as; Theory of constraints, Design of experiments, Lean production and Systematic layout planning were used as a foundation.

The project ended up with a conclusion that the process line should be able to meet the forecasted demand with the specified machines if sufficient buffer sizes are used between processes. The sufficient buffer sizes and the approximate needed operating times for each machine was found. Also it was found that it was possible to reduce one machine and still be able to meet the demand. The energy consumption for each machine was mapped out and the consumption for the whole system was simulated. Accordingly, the most consuming machines could be determined. It was found that some machines, performing the same task, consumed significantly different amounts of energy and that some machines are consuming approximately the same energy amounts independently on the machine states. Potentials for saving approximately 275 000 SEK in pure electricity costs were found. In the layout review, alternative layouts that can be beneficial compared to IAC's own proposal were found.

Contents

1 Introduction

This chapter introduces the customer International Automotive Components (IAC) and the background of this project. A description of the handled production system is also included in order to make the problem definition understandable. Also the purpose and the goals of the project are presented.

1.1 Background

IAC is a global company providing several vehicle manufacturers with interior components (IAC, 2013). In 2008, IAC build a new plant in Låssby, Gothenburg. The plant is providing Volvo Cars Corporation (VCC) with fully assembled cockpits and door panels in the same sequence as VCC uses in their assembly line. The cockpits and the door panels are delivered continuously to VCC just in time. The cockpits that are assembled at IAC consist of IAC's own manufactured instrument panels (IPs), which are manufactured in the same plant as the cockpits, and components delivered from external suppliers. IAC are keeping a buffer of IPs in order to ensure that the right cockpit can be assembled in right time, all the time.

In 2015 VCC will launch new car models which mean that IAC will launch new products as well. In order to manage the production of the coming IPs, some new machines have to be bought and a new line setup has to be done. The new line setup will require some internal buffers in order to ensure a stable production. Different product families (car models) are partly planned to be processed in common machines and that will result in a higher utilization of the machines that are going to serve several product families than the utilization of the machines that will only serve one product family. IAC have a planned machine setup but they wants to verify that the machine capacities will be enough to deliver the forecasted customer demand or if further investments needs to be done. Also they want to make an evaluation of the production flow dynamics in terms of buffer levels etc. The complexity in the process flow is high due to many different product variants that need to be processed in batches since they need different tool setup in some of the machines.

In today's society it becomes more and more important for companies to be aware of their environmental footprint. Leaving a big environmental footprint is expensive and will probably be even more expensive in the future. Therefore it is important to strive for a sustainable development where the negative effects on the environment is minimized or eliminated. That will also decrease the costs for the company. IAC have some equipment that consumes much energy, but exactly how much energy each process consumes is not known. They have a figure on the total consumption of the plant but since they are not completely aware of each process' consumption, it is hard to know where to put the efforts in order to decrease the biggest amount of energy consumption. For this reason IAC wants to increase their awareness of the energy consumption for the coming production line.

The 2015 IAC production line will be a combination of existing and new equipment. Therefore the layout of the plant needs to be modified. There are several aspects to look at when setting the layout of a factory and IAC wants to have external people's opinions about their plans. When working in a familiar area it is easy to forget some important aspect due to the history kept in mind.

1.2 Description of 2015 IAC production system

As mentioned in the background, the 2015 IAC production system will be a combination of existing and new equipment. This section describes how the production system are planned to be designed in terms of production sequence and how it will be managed in order to achieve a stable production.

1.2.1 Product variants

In total there will be a high number of different product variants produced in the system. However the minor variances (color etc.) that will not affect the production flow in any way are not considered. In order to make the understanding of the production flow easier, the variances that affect the production flow will be presented. The variances are basically options that the customers have to specify when ordering a product. The number of variants will increase as the product moves downstream in the production flow. Therefore the different variances can be divided into several levels. In Figure 1, the product variants with the corresponding demand distribution can be seen. The total number of product that are forecasted to be sold are 170 000 annually.

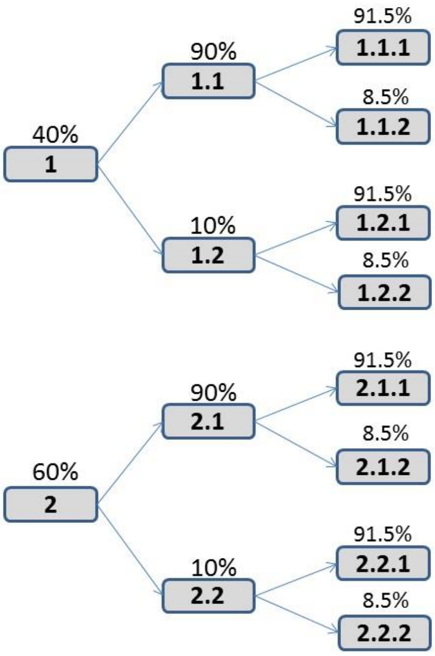


Figure 1 - Product variants with forecasted demand distributions.

There will be two different product families, 1 and 2 as shown in Figure 1. In the injection molding machine (Figure 2) there will be two options for each product family, which ends up in four variants; 1.1, 1.2, 2.1 and 2.2. In the foaming process (Figure 2) there will be two additional options for each of the already introduced variants, ending up in eight different variants which can be seen in Figure 1 above.

Variant 1.1.1 and 2.1.1 are the products that are forecasted to be sold in highest quantities, and according to that, they are mentioned the *high runners.* The other variants are mentioned as *lowrunners.*

1.2.2 Production flow

In Figure 2, the general flow for the production system can be seen. In order to decrease the number of terms used when talking about the system, names were given for some aggregated departments. Those can also be seen in Figure 2.

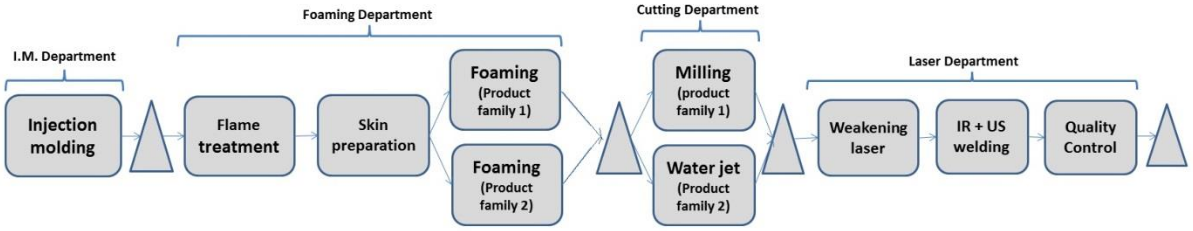


Figure 2 - Production flow including machines and departments.

The same injection molding machine will be used for all four variants. This means that only one variant can be produced at one time and when changing to a new variant a tool change will be required. The decision about when to change the tool will be done based on the downstream buffer statuses. When the product exits the injection molding it will travel to a buffer.

Next step in the flow chain will be the flame treatment. The flame treatment, skin preparation and foaming will be working in sequence. There will be two foaming machines, one for product family 1, and one for family 2. In each foaming machine there will be 4 tools that always are used in the same sequence. The tool setup can be changed depending on what products that are needed to be processed. However, the tool for the *high runner* at the foaming machine for product family 1, will always be used in at least 3 out of 4 tool places. The fourth tool place will be alternated between all four variants belonging to product family 1.The same concept will be used at the foaming machine for product family 2. The decisions about how and when to alternate the fourth tool is done based on what products that are needed in the downstream buffers.

After the foaming process, all products will go into a buffer. There is a technical restriction that states that the product must wait in that buffer for at least 45 min before they can be further processed.

When the products have waited for at least 45 min, they will continue to either a water jet machine or a milling machine, depending on if they belong to product family 1 or 2.When the products have been processed in either a water jet, or a milling machine, it will continue into a buffer.

The rest of the operations; weakening laser, US welding, IR welding and the quality control will work in sequence. However these machines require fixtures that can only fit to either product family 1 or 2 at one time. This means that the fixture setup will be alternated between the product families. The decision about when to change the fixture setup is done based on the finished IP buffer levels (the last buffer in Figure 2). When a product has passed the quality control, the IP is finished and will travel to a buffer and stay there until it is time to be assembled into a cockpit.

1.3 Problem definition

In the 2015 IAC production system, the machines in the injection molding and the laser department (Figure 2) will be used for two product families. However they can only handle one of them at one time. In order to store the products from an upstream process that cannot be processed in the downstream machine (due to tool configuration), buffers will be required. Due to the big differences in cycle times between the machines, some machines will be needed to run for a longer time than others. Also, two parallel flows (one for each product family) will go into one common, however only one product family can be handled at one time (in the common line) due to tool configuration. In order to not block the system, buffers will be needed to store products coming from a machine, whose downstream machine already have stopped for the day or have the inappropriate tool configuration. To decide how big these buffers capacities should be and how long time each process has to be run, are critical questions for IAC.

Also, due to the high number of product variants, it is important to ensure that it is possible to keep stable buffer levels for all variants without any shortages under the forecasted customer demand of 170 000 products annually.

In order to increase the electrical power utilization, it is important to be aware of the current consumption. Therefore, in order to decrease the energy consumption at IAC, it is important to know the contributors to the total energy consumption, which is not the case today.

When the new production line will be installed, some machines needs to be moved and the new machines needs to be placed somewhere. IAC have a rough plan for the layout of the system, but they want to get feedback from external eyes.

1.4 Purpose

The purpose of this project is to investigate the production flow dynamics of the 2015 IAC production system and evaluate how the planned equipment setup will meet the capacity demand. Also in the project the energy consumption will be mapped out with the purpose to explore possible energy savings and a review of IAC's planned layout will be done in order to provide IAC with feedback from external eyes.

1.5 Goals

The goals for this project can divide into its three main topics; production flow dynamics, energy consumption and plant layout.

Production flow dynamics

The overhead goal for the production flow dynamic topic is to analyze the production flow over time in order to ensure that the line capacity is enough. Also, the dynamics of the buffer levels over time will be analyzed. The concrete questions that should be answered are:

- What are the sufficient buffer capacities between the different processes?
- What are the required operation times for the different machines?
- Which production schedules can achieve a stable production?

During the project, additional questions emerged that were desired to be handled:

- Is there a need for an additional third milling machine?
- Is it possible to reduce the no. of water jet machines from 2 to 1?
- Will the system be able to endure higher customer demands than forecasted?

Energy consumption

The general goal of the energy consumption study is to generate valuable figures of the energy consumption of the system and to investigate if there are possibilities to make savings. The questions that will be answered are:

- How big is the energy consumption for each machine in the process line at different states?
- How big are the energy consumption and the CO2 emissions for the whole process line?
- Can different production strategies (batch sizes, production schedule etc.) result in decreased energy consumption?

Plant layout

The plant layout review will be done if there is enough time for it. The general idea of it is to provide IAC with feedback on their proposal. The following tasks will be handled:

- Create proposals for the layout on the floor level.
- Compare the proposals with IAC's proposal.

1.6 Delimitations

This project will only focus on the coming IP process line. Machine setup for the line is mostly specified, however if a reduction in investment can be done, that is not a restriction.

Existing input data regarding lead time, cycle times, etc. will be used (IAC's responsibility). However the data for the energy evaluation will be collected by the project members.

Only the electrical power consumption of the production system will be handled. No process emissions will be handled and also, no other gases than CO2 from the electrical power source will be considered in the energy consumption evaluation.

Major modifications of the layout are not practically possible to implement and will therefore not be considered. A specific area in the plant is available for the treated production system. It is not possible to use any other area of the plant.

2 Theoretical framework

This chapter presents theories relevant for this project. Since the project mainly consists of three different topics, theories for those are presented under corresponding headline. Both theories for how to handle the problems as well as theories that supports the analysis and evaluation phases are presented.

2.1 Production flow dynamics

The main topic for this project is production flow dynamics. This means how the status of a production system continuously changes over time. For example how buffer levels changes due to disturbances such as breakdowns etc. How a production system reacts on such dynamics can be complex to investigate without using a proper tool. For being able to handle the dynamics, a suitable tool needs to be used. This part presents some different theories useful for increase the understanding of the dynamics in a production flow. Also theories that can be useful when evaluating critical questions regarding production flow are presented.

2.1.1 Discrete event simulation (DES)

Discrete event simulation is a process where the logics and sequences in a system are coded into a model in order to simulate the real system. DES is a powerful tool for creating a dynamic model and by that gain understanding of the dynamics in a complex production system. Also it can be used for investigating the result of strategy changes, investments etc. (Techtarget, 2012).

According to Robert E. Shannon (1975), simulation means *"the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system."* (Ingalls, 2011).

A discrete event simulation model can handle the dynamics in a system since the variables in the model changes independently on each other and the current state of the system. This means that random happenings such as break downs, disturbances etc. can be simulated in an independent way which is preferable when simulating a production system (Ibid.).

There are several softwares available for creating a DES model. However they have mostly the same components. The main components in DES software are: entities, activities and events, resources, global variables, a random number generator, a calendar, system state variables and statistics collectors (Ibid. p.8).

In order to achieve an accurate simulation model, it must be constructed in a reliable way. This means that the constructor must identify; the logic in the real world system and what data that needs to be collected. Most simulation project starts with conceptual modeling to gain the basic knowledge of the system that is going to be simulated (Robinson 2010, p. 8).

Conceptual modeling

When a discrete event model of a production system shall be created, the first task is mostly often to create a conceptual model of the treated production system. The conceptual model is a software independent abstract that converts the real world system into a documented theoretical system. The end result for a DES project is often highly dependent on the quality of the conceptual model (Ibid. p. 3).

There is no right or wrong conceptual model for a specific real world system. The design of it shall be a result of what the aim of the simulation study actually is. Depending on what is going to be studied in the model, the level of details in different aspects can vary. For example if an analyze of the utilization of the labor shall be done, it is important to include the manual work on a detailed level, while if the maximum output from a production system will be studied, then the requirement of details in manual work probably can be lower. The level of details in a simulation model shall not be higher than required because that will result in a higher risk of making mistakes, requires more time and resources and the risk of non-available data will increase (Robinson 1994, p. 34).

This means that it is important to define what the requirements of the model are. What input variables are relevant to easily be able to change and what output variables shall be easy to export. These are the two main questions that the modeler has to answer together with the project customer. If the inputs (experimental factors) and the output of the model are well defined and easily available, it will ease the experimental and analyzing phase of the simulation project. Also the actual modeling (coding) phase will be more time efficient performed if the conceptual model clearly defines the level of details, the relevant experimental factors and the scope of the model etc. (Robinson 2010, p.14).

The conceptual modeling phase is often an iterative phase and especially when the modeler is non-familiar with the real production system. In that case it is important that the modeler understands the logic in the production system and the actual problem situation. The conceptual model has to be continuously revised throughout the modeling phase (Ibid. p.10).

The data gathering and collection phase is directly connected and dependent on the conceptual modeling and the level of details.

Data gathering

Data gathering is considered as a critical step during the construction of a simulation model. The model validity and reliability is depending on the input data. The data gathering step includes identification, collection, analysis and storage of all relevant input data for the model. Identifying the relevant parameter for the simulation model can be a problem due to high system complexity and selected level of detail. Studying the system closely by observations and interviews and identifying the desired level of details from the beginning will minimize the collection of irrelevant data. The data types are varying from data that are available for gathering, data that are not available but can be gathered and finally data that are not available and not either collectable. Classifying the data into those categories and set a plan for how to collect and evaluate them saves time and leads to accurate input data (Skoogh and Johansson, 2008).

2.1.2 Lean buffering

The dynamics in a production system creates the need of having buffers in between the different processes that contains both unfinished as well as finished products. The existence of those buffers enables the system to handle the customer’s demands and to compensate any losses in the throughput (Enginarlar, 2003). On the other hand, according to lean philosophy, having excess buffer levels is considered as one of the main seven wastes in manufacturing. It increases the cost associated with each product, leads to quality problems, tying up capital and it prevents the creation of continuous and visible flow. Choosing the optimum buffer capacities that are needed in order to achieve the desired production rate and keep the customer satisfaction is an effort towards waste elimination and applying lean thinking (Nicholas, 2011, p.57-87).

2.1.3 Theory of constraints

The theory of constraints (TOC) is a philosophy that is often used in combination with discrete event simulation modeling when trying to improve the production system. The theory is aimed for increasing competitive advantages in a production system (Rahman 1998, p. 336).

A constraint is something that is limiting the system from reaching higher performance. According to TOC there always exists at least one constraint in a system; otherwise the system would give infinite profit. The constraints are opportunities for improvements according to TOC (Ibid. p. 337).

The concept of how to improve the system according to TOC can be seen in Figure 3 below.

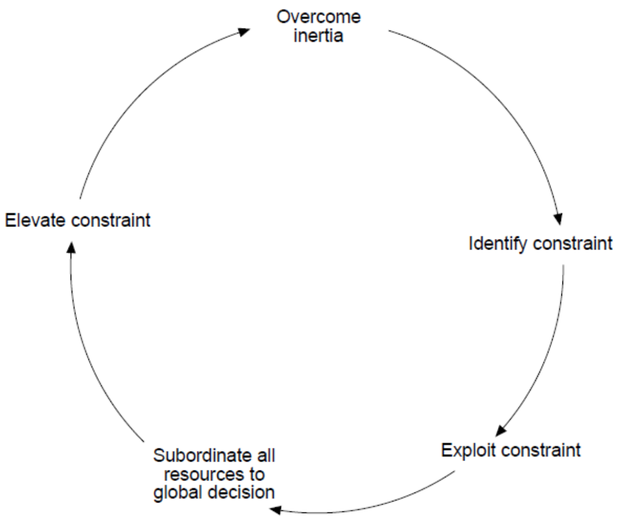


Figure 3 – Theory of constraints procedure (Ibid. p. 338).

The first step in the improvement process is to identify the constraint(s). These can be both physical and managerial. Often a physical constraint can be determined by having higher stress level (utilization) than other machines. Also big queues before the resource and small queues after the resource can be indications for a constraint (Ibid. p. 337).

When the constraint(s) are found, efforts must be put on trying to increase the throughput of the constraints. If it is a physical constraint, attempts to exploit it must be done. If it is a managerial constraint, then a policy must be developed to overcome the constraint (Ibid. p. 337).

The third step says that all non-constraints must be adjusted in order to serve the constraints as much as possible. Increasing the throughput of a non-constraint will only have effect of higher inventory level (Ibid. p. 337).

If the previous constraint still is the constraint, then more efforts have to be put on trying to improve the performance of it. If the constraint is improved enough then the constraint will move to another function (Ibid. p. 338).

The last step of the continuous TOC loop says that a solution is never lasting forever and in all situations. Different business environment puts different demands on the system. If something is changed in that aspect, the process has to be repeated from step 1 (Ibid. p. 338).

2.2 Energy consumption

Evaluating the energy consumption of the 2015 IAC production system is the second topic in this project. The following section introduces the theory behind the importance of keeping a sustainable development and striving for decreasing the consumption of energy. Also, theories about how to investigate energy consumption are presented.

2.2.1 Sustainable development

Sustainable development (SD) has been defined in several ways. However the most common definition is;

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- *the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and*
- *the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."* (Iisd, 1990).

Economic, social and ecologic sustainability are all included in SD (Figure 4). To understand SD, the world must be seen as a system that connects space and time. When looking at the world as a such system it can be understood that for example air pollutions somewhere on the earth affects the rest of the world and that decisions regarding technical development, taken by the previous generation, affects the coming generations (Ibid.).

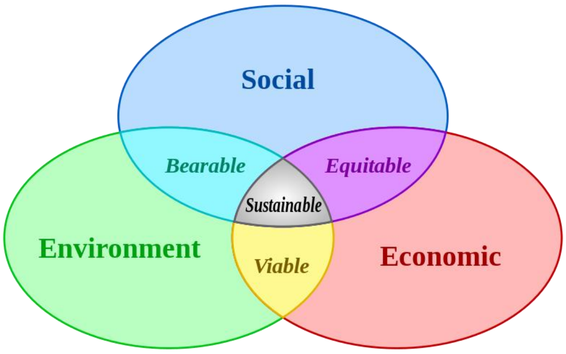


Figure 4 – The three sustainability aspects (http://commons.wikimedia.org/wiki/File:Sustainable_development.svg).

SD is a global strategic vision to meet the economic, social, environmental and technological challenges in the world. The key challenges are; globalization, climate change, ageing population, public health, poverty and social exclusion, loss of bio-diversity, waste volumes, soil loss and declining fertility and transport congestion. Engineers have a big responsibility since they can affect many of these key challenges. To design products with an improved usefulness and processes with less negative impact on the environment are challenges that are important for the engineers (Jovane et al. 2008, p.643).

In this project all three aspects of sustainable development will be covered. The production flow dynamics are mostly affecting the economical aspect, the energy consumption are affecting both the economic as well as the environmental aspect. The plant layout is affecting social environment for the operators and it also affects the economical aspect.

Manufacturing industry's role

Manufacturing industry has a great role in today's society. Since the industrialization started, the manufacturing industry has generated wealth, jobs and quality of life (Ibid. p.645). But at the same time, industry has negatively affected the environment. The use of the world's resources has been more than doubled during the last 50 years and today the ecological footprint from humanity is bigger than the world can provide (Ibid. p.644). Manufacturing industry can contribute to a decreased human footprint by develop its processes in order to:

- decrease/eliminate the material waste or recycle on site,
- eliminate chemical substances that can be hazardous for humans or the environment,
- conserve materials and energy and use the most suitable form of energy and material for the purpose,
- minimize or eliminate chemical, ergonomic and physical hazards caused by bad work spaces (Ibid. p.647).

Manufacturing is a backbone for the growth in terms of wealth producer, job generator, and human and physical resource user. Therefore it is important that the manufacturing industry can increase their competitiveness in all sustainable development aspects (Ibid. p.647).

2.2.2 Ecological aspect in DES

It is important to be aware of the energy consumption in a production system in order to know where to put the efforts to decrease it as much as possible. The recent years, the usage area of DES have extended from mostly focusing on economical sustainability to also include the ecological aspect. In order to include the ecological aspect in a DES, additional data have to be gathered such as process emissions, electrical consumption etc. (Skoogh et al. 2011).

The electrical power consumption is a result of discrete events, which makes DES being a suitable tool for investigating it (Techtarget, 2012).

When gathering the data for the ecological aspect it is important to decide if the data will be regarded as deterministic or stochastic data. Much time can be saved if most data can be seen as deterministic variables. However, in order to represent the reality in a proper way, it must be ensured that the deterministic data are valid and that there are not to big variations for example between each production cycle. If the data can be regarded as deterministic, it is enough with a few data samples to construct representative data (Skoogh et al. 2011).

2.3 Plant layout

The third, and the smallest topic of this project is layout planning. The following section presents some important aspects to study when designing the layout of a factory.

A production system is considered as a set of interactions of different objects that have different functions such as personnel, machines, material etc. The workplace in a production environment has a big role towards achieving the organization's goals by integrating those parts smoothly (Loun et al. 2013, p. 47). Keeping the interest on having a good workplace is an urgent demand to increase the company's competiveness in producing products with better quality, cheaper price, in shorter time, and higher flexibility to changes in demand (Nicholas 2011, p.1-17). A good workplace increases the opportunities for the company to improve their throughput using existing resources and space or making investments in the right directions (Mohr and Willett 1999, p.5).

Improving the layout can be done by taking into consideration different aspects or strategies:

2.3.1 Lean production

The aim of the lean philosophy in production systems is to maximize the throughput by using the least possible resources and make the production more efficient (Nicholas 2011, p.57-87). That is achieved by continuous improvement and elimination of the source of wastes. According to the Toyota production system philosophy (Liker & Meier, 2006), the main wastes in production are:

1. *Overproduction:* Producing more than needed.
2. *Waiting:* When there is a need for waiting before continue working/processing.
3. *Transportation:* Moving parts between different places or processes.
4. *Overprocessing:* Spending more time in an operation than is actually needed.
5. *Excess inventory:* Having more inventory than needed (internal buffers, finished products storage etc.).
6. *Unnecessary motions:* Workers are doing motions that are not adding value.
7. *Defects:* Producing parts that need to be scrapped or reworked.
8. *Unused employee creativity:* Not using the creativity and the experience from operators.

Especially waste nr 3 and 6 presented above will be important to consider in the layout topic of this project.

Lean philosophy also states that the production flow should be visible where everything is settled in place with a clear indication. A visible flow has a great impact on the workers in terms of increasing their awareness about the flow and makes it easy for them to monitoring it. It also helps the workers to take immediate action in case of discovering defects or quality errors and it results in a better communication for example in case of overproduction, disturbances etc. (Nicholas 2011, p.57-87).

Waste number 8 mentioned above is an important aspect in lean philosophy. Involvement of the operators and creating an ethical work environment is advocated.

2.3.2 Human needs

To understand the human's needs when designing the layout for a production system, helps to create prerequisites for the workers to be productive and motivated. Humans have a need of belonging. A good workplace should enable the operators to communicate with each other in an easy way. That is mostly preferable done by standing close to each other in a way where one can see each other. If a social environment is achieved, the workplace will be safer since it will gain the monitoring of each other (Changingminds, 2013).

Also, people are more motivated if they feel that they have control of their workplace. Therefore it is important to have a layout design that allows the operators to overview their working area and to get feedback on the status of it (Ibid.).

3 Method

This part describes what methods that were used in order to handle each part of the project. The chapter is divided into the three main topics of the project; production flow dynamics, energy consumption and plant layout.

3.1 Production flow dynamics

In order to handle the goals regarding the production flow dynamics, the following methods were used:

3.1.1 Discrete event simulation

According to the problem definition, the main purpose of the project was to study the production system's dynamics and trace up the buffer behavior during different running scenarios. The dynamic capability in DES enables to study this in an easy and suitable way. DES is preferable in order to understand complex systems that involve different logics such as different variants, tool changes, buffer level variations etc., which is the case at IAC. Having a virtual environment makes it easy to perform different experiments by changing the input variables and notice the response change.

Banks methodology

Banks methodology (Figure 5) is a procedure that helps to perform a DES project in a structured way. It is a software independent method that consists of seven steps that are important for achieving a successful DES project. (Banks et. al 2001, p. 16)

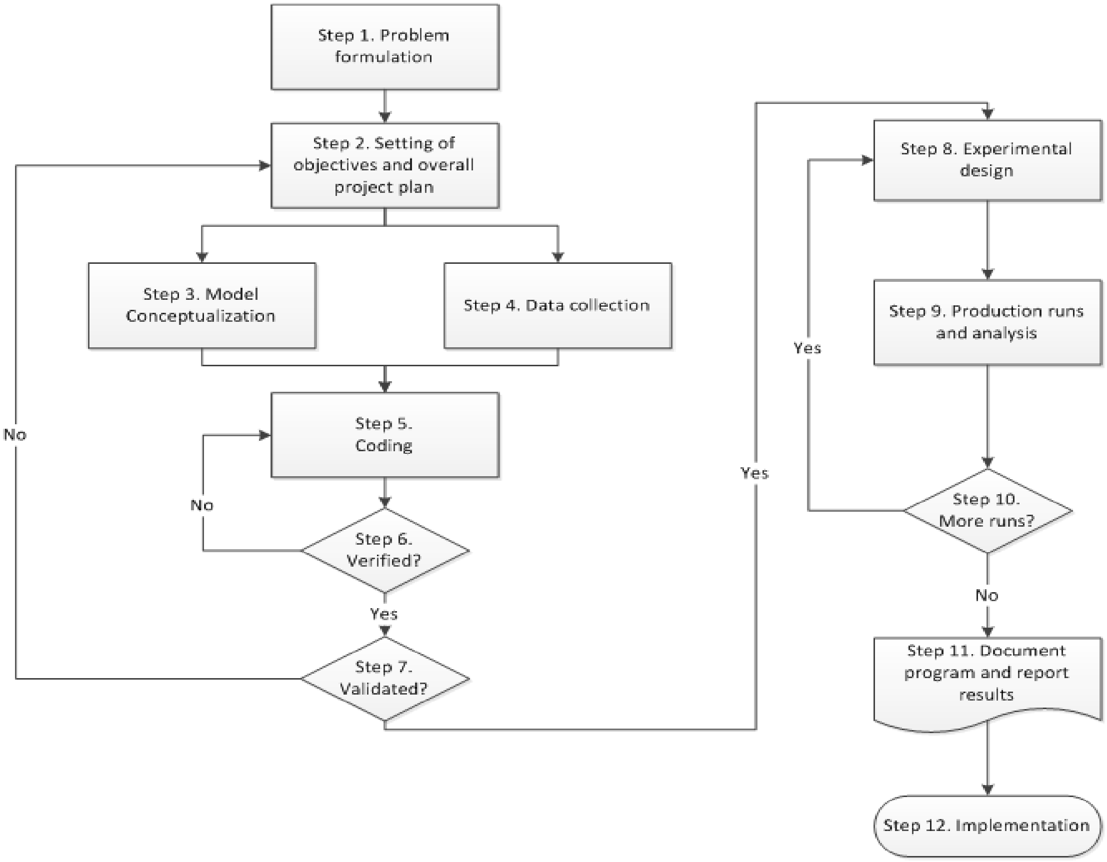


Figure 5 – Banks methodology (Ibid.).

In order to keep a structured work progress, it was decided to follow Bank's methodology.

Data gathering for DES model

As the production system that were going to be simulated was a future production line, the type of input data varied from data that was already available (cycle times, setup times etc.) on the databases and data that were not available and needed to be either collected or estimated (conveyor distances, conveyor speeds, energy data etc.). The methodology introduced by Skoogh and Johansson, (2008) is proposing a guideline for input data management for DES. It explains the data collection step in banks methodology in a more detailed and procedural way. This method was partly followed but some minor changes were needed to be done in order to fit to this project.

Design of experiments (DOE)

In order to keep a structured way of analyzing the goals and to understand which factors that are more influencing the response than others, DOE was used. DOE also enables to discover the interactions between the different factors. DOE constructs all possible combinations of the input variables by using different values for each factor within its value span. A change in the response happens when the interaction between the different values of the factors occurs (Telford, 2007).

3.2 Energy consumption

In order to evaluate the energy consumption of the production system, some methods were chosen to be used. Since a DES model should be created, it was decided to use it also for the goals regarding energy consumption. However, the model needed to be complemented with some data. A method by Skoogh et al. (2011) was used in order to gather that data.

3.2.1 Energy data gathering

Studying the machine's energy consumption was a part of the project goals. Being able to do that required more detailed investigation for each particular energy consumer. The machine's states (busy, idle, setup, etc.) and cycles always varying during time and that leads to electrical power variations as well. Skoogh et al. (2011) specifies the way of how to represent the electric power in a DES model. They proposed the method for data collection, the number of samples needed and how the deterministic and stochastic parameters should be represented. The power measurement was performed by using a certain device that could track the three electrical phases at the same time and record the power at a chosen frequency. Skoogh et al. (2011) recommended to measure each machine as one unit and include overhead contributors such as machine light etc.

3.3 Layout planning

The layout study was performed in a simplified way. Since some equipment (conveyors and buffers) were not completely designed, they could not be included in the layout study. However the conveyors and buffers should be placed in the ceiling, which means that the floor space could be studied in a more detailed way. An easy method was introduced to study the layout called "Simplified systematic layout planning" (Mohr and Willett 1999, p.5). Due to the simplified level of this study, and the limited time, this method was suitable to use.

The method enables the integration of different evaluation factors on which you can rate your layout proposals, it is also taking into consideration some detailed technical information such as ventilation, water, etc. The method enables the user to identify the relations between the different functions and grade the importance of those relations. The next step is to identify the space area required for each function and what essential features that are needed to be included there such as electricity, ventilation, compressed air, water and drain etc. Based on those previous steps, different proposals can be generated and evaluated based on the chosen evaluation criteria.

4 Work description

This chapter presents how the project was performed and how the methods were practically used. The project consisted of three main topics; production flow dynamics, energy consumption and plant layout. The sequence of these topics was performed according to the demand from the customer IAC. Since the most time critical topic was the production flow dynamics, the project started with this.

4.1 Production flow dynamics

This section describes the different phases of the first topic in the project; production flow dynamics. It starts with describing the steps about how the model was created and how the dealing with the data and some simplifications was done. The target with that was to make the model be able to handle the different project questions. The second part in this section presents the work procedure used to be able to answer each question under this topic.

4.1.1 Building the DES model

This section shows the important steps followed in order to create a reliable DES model which should be the foundation for the analysis and fulfillment of the project goals.

Understanding the system and data gathering

The first step in order to understand a production system that does not exist yet is to hold meetings with the experts who are responsible for it. The output of those meetings gave a figure about the production system, the products itself and all the technical issues associated, the number of variants and how they differ from each other and at which process step the variants are created. Spending time on the production floor and following machines and flows that are similar to the future line's, gave more obvious picture and imagination about how the new line will be. Analyzing the available data for cycle times and the yearly demand gave a clear view about the system bottle neck points. Working in parallel with data gathering enhanced the understanding of the system which enabled to list down all the data required for the simulation model. As it was agreed from the beginning that IAC should be responsible for the data such as cycles times, setup times, etc., no time were spent on verifying those data. There were some data that needed to be assumed. For example the target OEE was decided by IAC's engineers, warm up time for the machines was gathered by interviewing operators on the production floor and the conveyor speed and distances was estimated by doing some rough measurements on the production floor.

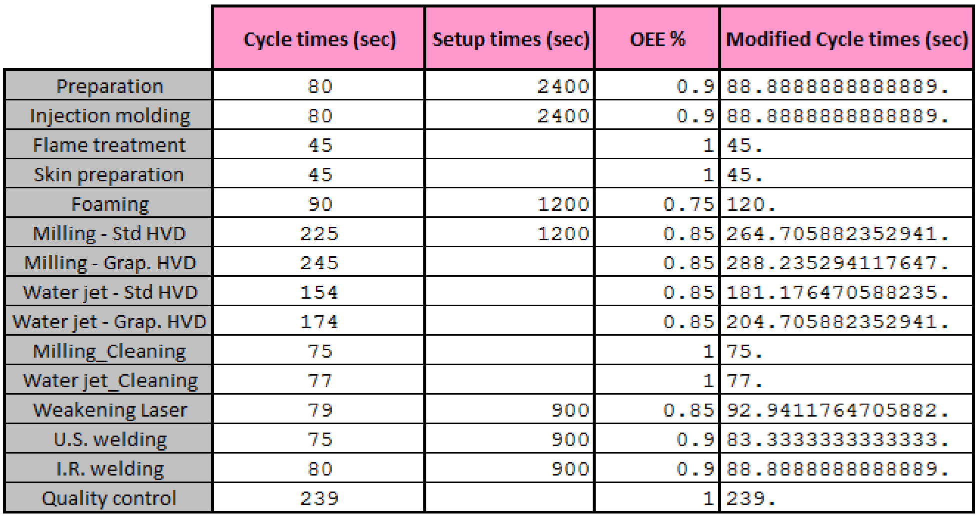
Create the problem frame and conceptual modeling

Getting a good understand of the system enabled to formulate the problem in a clear way and understand how to relate the goals to the problem. Some critical questions that needed to be answered in the beginning were preventing the formulation of the problem due to the absence of a clear picture about how the system should be. For example how and when it will be decided to change from one tool setup to another and how that should be represented in the simulation model, whether to include the manual work in the model or not which will increase the level of detail, determination of production sequence and batch sizes and how to evaluate the buffer capacities. Understanding the system led to removal of confusion and formulated the problem frame.

The next step was to create a conceptual model for the system which shows the basic production flow including the machine sequences, places for buffers and the critical buffer points which was the main focus of the analysis. Developing the conceptual model took place in parallel with getting more understanding for the system as well as creating the problem formulation. The conceptual model was complemented with the different logics in the system such as; how the decision will be taken for changing the tools and the relation between different buffers. The conceptual model was a simplified way to demonstrate how the simulation model should works and a tool for communication with the company. The conceptual model also worked as a foundation for the construction of the simulation model as described in the theory section *2.1.1.*

User interface

A simple user interface was created using Microsoft excel which was directly connected to the simulation model. It enabled to change most of the basic data, such as batch sizes, demand, variant distribution, cycle times for the machines and the OEE (Overall Equipment Efficiency: A measure of machine efficiency), in an easy way. It also provided the ability to change the production schedule and the power consumption data which helps to make different experiments and trials. An example of the user interface can be seen in Figure 6.



	Cycle times (sec)	Setup times (sec)	OEE %	Modified Cycle times (sec)
Preparation	80	2400	0.9	88.8888888888889.
Injection molding	80	2400	0.9	88.8888888888889.
Flame treatment	45		1	45.
Skin preparation	45		1	45.
Foaming	90	1200	0.75	120.
Milling - Std HVD	225	1200	0.85	264.705882352941.
Milling - Grap. HVD	245		0.85	288.235294117647.
Water jet - Std HVD	154		0.85	181.176470588235.
Water jet - Grap. HVD	174		0.85	204.705882352941.
Milling_Cleaning	75		1	75.
Water jet_Cleaning	77		1	77.
Weakening Laser	79	900	0.85	92.9411764705882.
U.S. welding	75	900	0.9	83.3333333333333.
I.R. welding	80	900	0.9	88.8888888888889.
Quality control	239		1	239.

Figure 6 – Machine data form from the user interface.

Simplification for simulating conveyors and buffers

IAC's production system will be designed so that the conveyors between the different processes will act as buffers where the products will be stored as well as transported. The path of the conveyors will be moving through the factory roof going down to each process. To be able to simulate the conveyor system as it should be in the reality some detailed data were needed such as the path and distance of the conveyors, speed, the required distance between each product, detailed dimension of each product variant, 3D cad drawing of the conveyor system, etc. These detailed data were not available and not possible to gather. To simulate the conveyor system in a detailed way would be time consuming, and the benefits of it should not be significantly. Instead, an easy way to deal with the conveyor system was proposed which could lead to mostly the same result. Figure 7 shows a simplified way for considering the conveyor system in the simulation model as a normal buffer with certain capacity. It considers the distance before the buffer and after the buffer and how much products should be there. However it does not consider the buffer path itself, only its storage capacity. This simplification made it easy to trace the buffer levels and utilization.

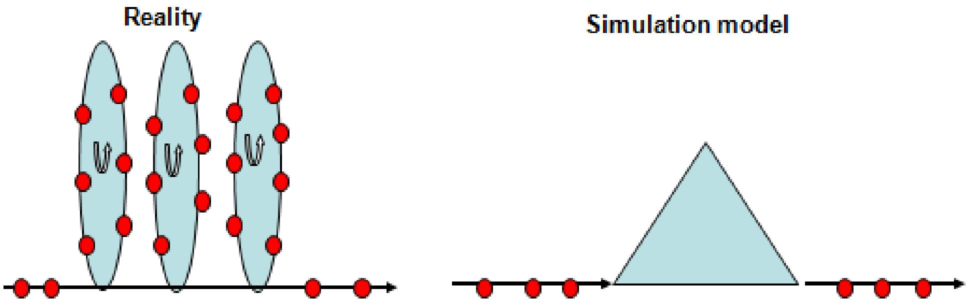


Figure 7 – Simplification for the conveyor system in the DES model.

Representation of the cycle times, breakdowns and OEE

As it was decided that the model should not include the manual work associated to the cycle times (such as loading, unloading, etc), the cycle times for each machine was represented in the model using a constant number with no distributions. However, the cycle times were different for some of the product variants. Representing the breakdowns for each machine was a problem as some machines did not exist yet so it was hard to estimate this data. The same problem occurred for the scrape rate. Instead it was decided to represent both breakdowns and scrap rate in terms of OEE. In the model, the cycle times for each machine was divided by the OEE value, resulting in longer cycle times which compensates for the breakdowns and scrap rate. Due to this simplification, the simulated buffer dynamics were probably lower than the reality will show.

Representation of the decisions taken by operators

The operating logics at IAC's production system is differs between taking decisions regarding tool changes of the machines which means switching between different product variants and adjusting the production sequencing according to the buffer levels. The basic criteria at which the operator take the decision to change between product variants is the levels at the finished IP buffer. The buffer level for each variant in the finished IP buffer is monitored by an operator. The operator takes decisions about what the upstream buffers needs to deliver to the operations. Also by monitoring the buffer levels for the variants, decisions about changing tools in the machines can be done. In the reality the interval between changing the tools will be random depending on the variant's buffer levels and the demand. However, it was estimated by the IAC engineers that the average interval between tool-change will be approximately four hours. So it was decided to make a simplification in the simulation model that the decisions regarding changing the tool should be taken every fourth hour. The decisions in the model were made based on an algorithm developed in order to mimic the operator's decision criteria.

4.1.2 Analyze the questions of the production flow dynamics

This part explains the procedure of analyzing the questions presented in Section *1.5*.

What are the required operation times for the different machines?

In order to keep a structured work progress, a procedure sequence was developed (Figure 8). As Figure 8 shows, the first tasks were to define the goals and the most influencing factors for the system's output. The focus for this analysis was to find out the required operation times for each machine in the system.

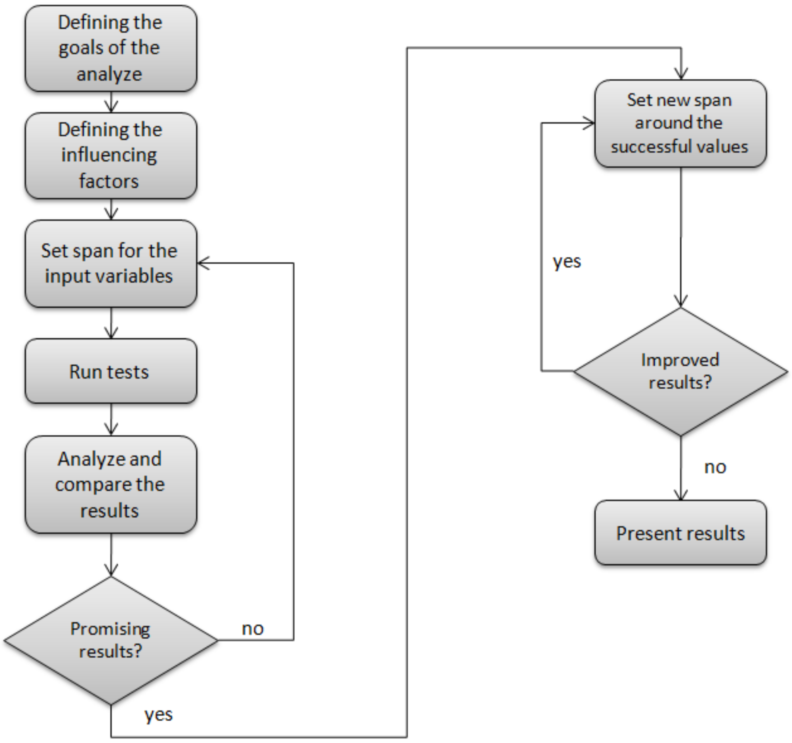


Figure 8 – Procedure for analyzing the required operation times.

In order to verify that the factors that were expected to influence the system really did, a *design of experiments* (DOE) was performed. The factors that were interesting and expected to influence the system response were the buffer capacities, machine operation times and number of milling machines. However all of those factors are highly dependent on each other. To make the analysis less complex, it was decided to put the buffer's capacities initial values to infinite. The five factors that were studied in this step are defined in Table 1. A maximum and minimum value for each factor was defined. All the operation times had the minimum operation time of 8 hour per day since it must be at least one shift per day and the maximum value was set to 24 hour per day since that is the maximum available time for per production day. According to the company the options were to have either 2 or 3 milling machines. Therefore the minimum and maximum values for that factor were set to 2 and 3 respectively. Each existing combination was constructed and resulted in a 2^5 factorial experiment.

Table 1 – Influencing factors and their minimum and maximum value.

no.	Factors	Min. Value	Max. Value
1	No. of milling machines	2	3
2	Operation time for Cutting part [hours]	8	24
3	Operation time for Foaming part [hours]	8	24
4	Operation time for injection mold [hours]	8	24
5	Operation time for Laser part [hours]	8	24

In order to see the influence of each factor, a response had to be created. The response should show how stable the finished products buffer level was during time. To get that response as a number, the standard deviation of the finished product buffer level for the *high runner* product variants was calculated (Figure 9). To get a relevant standard deviation value, the target buffer level for each variant was used as the mean value for the standard deviation calculation. To make it easier to read the response the two standard deviations were aggregated into one by taking the mean value of them.

The reason for choosing to trace only the *high runners* was that the logic in the model was designed in a way that the over/under production mostly could be obtained on those.

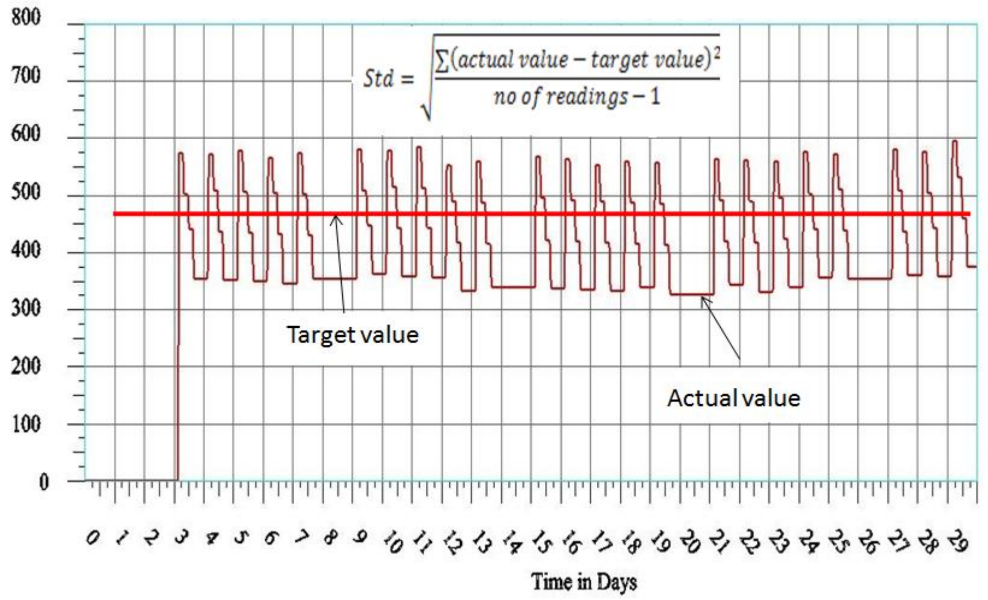


Figure 9 – Standard devation for the buffer level.

When the test was done using the different combination from the data in Table 1, the influence of each factor could be studied in a Pareto chart (Figure 10).

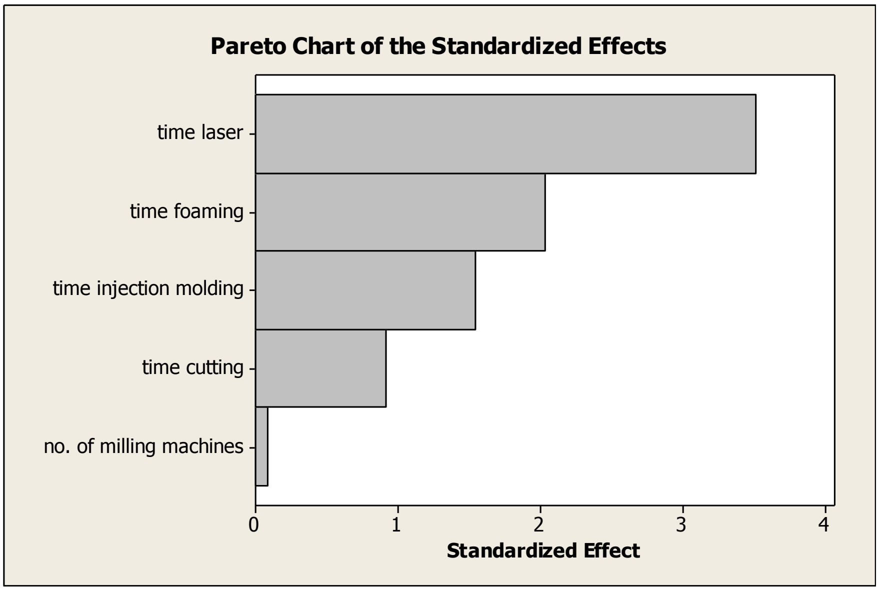


Figure 10 – Pareto chart for the influence factor's effect.

The Pareto chart shows that the effect of varying the laser department's operation time is influencing the response most significantly.

When it was verified which factors that were really influencing, the target was to find out the minimum required operation times for each machines. The first step was to set an initial span for the operation times for each department. The theoretical possible time span for the operation time of each department is from 0 to 24 hours. However, to save time, a rough number of how long time each process should be needed to run could be estimated. The calculations that were done in order to estimate the initial operation time spans were done by taking the daily demand times the cycle time for each machine. Then by taking that theoretical value plus/minus some hours, initial time spans for each department could be calculated. Those calculated values can be seen in Table 2.

Table 2 – Initial spans for the operation times for the departments.

Department	Min. operation time (hours/day)	Max. operation time (hours/day)
Injection molding	19	22
Foaming	16	18
Milling	14	18
Water jet	14	17
Laser	20	22

By using the software Autostat, all operation time combinations for different machines could be simulated in order to find values that made the system keeping a stable finished products buffer. The Autostat runs gave a rough indication on which machine operation times that were suitable. In order to refine the result, several trials and iterations were done where the operation times were justified around the values given by Autostat. TOC was used as a guide when adjusting the operation times. For example, if an internal buffer seemed to decrease its level during time as shown in Figure 11, it was an indication that the upstream machine's was a bottle neck and the operation time needed to be increased.

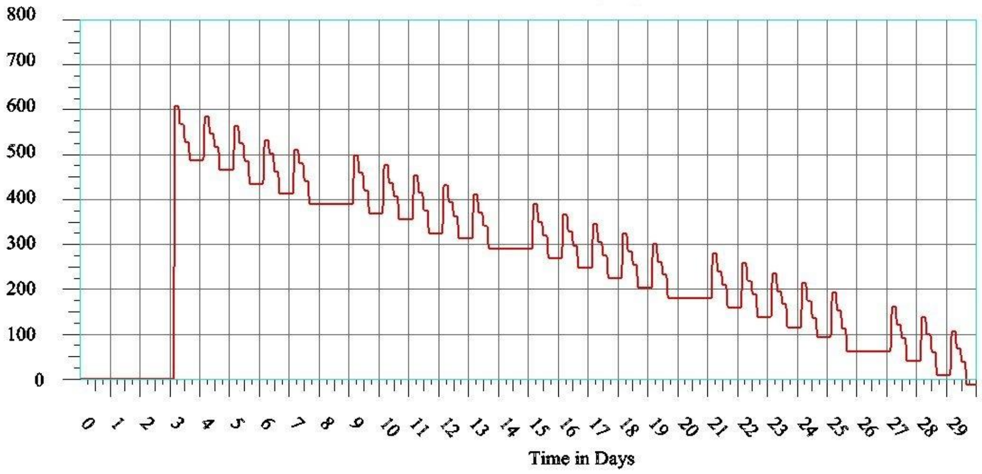


Figure 11 – Decreasing buffer level indicates upstream bottleneck.

It was chosen to use 1 hour as the step length within each span. This resulted in 720 different combinations to simulate in the analysis in Autostat. The analysis resulted in an indication of which operation times that were suitable in order to achieve a low standard deviation of the finished products buffer (the response). However, the response was not able to answer if the internal buffer levels were increasing or not. Therefore all the cases where the response reached a promising level had to be studied more in detail. After an iterative work procedure, minimum operation times that made the system producing with a suitable output of each department could be found.

What are the sufficient buffer capacities between the different processes?

In order to get the simulation model work, a warm-up of the system was required. During the warm-up, products were created to the internal buffers. When the warm-up was over, a certain level of products were placed in each buffer. This level can be called the startup level. In order to ensure that the system is not restricted by to low startup levels, big startup levels were used initially. In order to find out the minimum required buffer capacities, the startup levels were decreased iteratively, until each product variant reaches close to its shortage level as shown in Figure 12.

When the operation times were adjusted so that both the internal and the finished products buffer kept a stable level during time, the required buffer capacities could be studied. Bigger buffers than needed are not desirable according to Lean buffering. By studying the total buffer level at each buffer, the required capacities could be obtained.

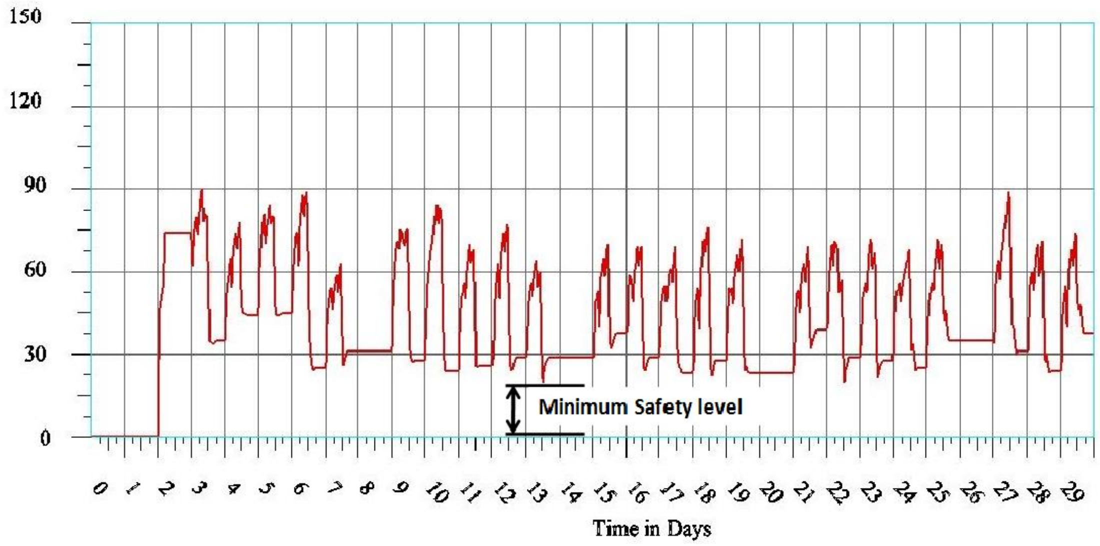


Figure 12-Minimum safety level for the products in a buffer.

Which production schedules can achieve a stable production?

In order to achieve as suitable shift time as possible for the some machines that exceed the normal shift times; the weekly required operation times were redistributed, resulting in a new production schedule which was tested. The evaluation of each production schedule was done by looking at the level at the finished IP's buffer and for the buffers between the processes as well if they are stable or not.

Is there a need for an additional third milling machine?

In order to investigate if there was a need for a third milling machine or not, firstly the number of milling machines as an influence factor was evaluated to find out if it was affecting the response or not as shown in Table 1 and Figure 10. Also, the required operation times that was obtained from the analysis result using two milling machines, had to be tested using three milling machines as well and notice if that affected the system response or not.

Is it possible to reduce the no. of water jet machines from 2 to 1?

It was a demand from IAC to check if it is possible to get rid of one water jet machine and see how the system will respond to that change. The analysis took place by changing the number of water jet machines to one and testing the system using the obtained operation times from the result using two water jet machines. Some modifications had to be done in the operation times in order to adjust the system to this new configuration. TOC was used in parallel while looking at the system response until reaching the last permissible modifications.

Will the system be able to endure higher customer demands than forecasted?

This study was done by increasing the yearly demand to 200 000 products annually, keeping the same distribution between the different variants and testing how the system reacted to that. To be able to run the system under these conditions the operation times for the different machines had to be adjusted in order to reach the stability in the different buffers if possible.

4.2 Energy consumption

This section describes how the performance of the energy consumption evaluation of the coming production line was carried out. It started with a research about how to measure electrical power consumption. It ends with presenting the way that the goals under the energy consumption topic were studied.

4.2.1 Develop the model in order to work with energy questions

The section describes the way to develop the model to be able to handle the questions under the energy consumption topic. It starts by showing the way for data gathering and then the implementation to the DES model.

Data gathering

The electrical power consumption of the machines in the production line should be measured at some different states. The equipment that was used for this task is named PowerVisa by Dranetz (Figure 13).

Figure 13 – Energy consumption measuring equipment by Dranetz. (http://www.calvan.se/produkt/3108300)

The device was connected to the incoming 3-phase wires for each machine. When the device was recording, notes were taken on what happened in the machine (state, disturbances etc.) at each time, using a clock that was synchronized with the PowerVisa device's clock. For some machines, it was several energy consumers with different incoming electricity wires. Since only one measuring device was available, several measurements had to be done, one on each energy consumer. Then it was important to synchronize the different measurements in a proper way in order to summarize the total consumption for each machine state.

All machines that were going to be used in the coming production line were measured. However there were three machines that did not exist yet; the flame treatment and the US- and IR welding machines. For those machines the data was not possible to measure.

When all data was gathered, it was studied and due to the low variance between cycles, it was decides to represent the data as deterministic (Skoogh et al. 2011). Average values for each state was calculated and documented in a way that was suitable to fit the DES model.

Implementation to DES model

As mentioned in the previous section, the energy consumption data was handled as deterministic, which means that each state always has constant power consumption at a specific machine. The DES model was coded in a way, making the energy consumption for a specific machine increase by a certain amount each time a product is processed or a tool change occurs. Each hour, the program calculates the amount of idle time and adds the corresponding energy consumption to the hourly consumption for the specific machine. The hourly consumption for each machine is summarized in order to generate the total energy consumption during the simulation time. When the machines are not used at all, a standby consumption is added for the machines that include some robot (since the robots needs some power in order to not lose their calibration).

4.2.2 Analyze the questions of the energy consumption topic

This section describes the way the different questions under this topic were handled.

How big is the energy consumption for each machine in the line at different states?

In order to map out the total energy consumption for each machine and in total, the DES model was run for a specific time and the result was easy to pick out. The energy that each product on average needed (including idle times, tool changes etc.) for being processed in the line could also be calculated easily by taking the total energy consumed during the simulation divided by the total number of products produced during the same time.

How big are the energy consumption and the CO2 emissions for the whole line?

When the energy data in Table 7 was implemented into the DES model, a simulation with the operation times proposed in Table 4 was done. The simulation provided data about the hourly as well as the total energy consumption for each machine as well as the system in total. By dividing the total consumption by the number of products produced, the average consumption per products could be calculated.

Can different production strategies (batch sizes, production schedules etc.) result in decreased energy consumption?

When different production strategies should be evaluated, it was needed to define what different factors that should be investigated. Also the relevant spans for those factors were set. After that, combinations of all the factors were constructed (DOE) and simulated. In some situations, small modifications of some operation times had to be done in order to make the system fulfill the basic criteria; to keep a stable production according to the forecasted demand. When all combinations were simulated and the result documented, it was easy to compare and see the result. The factors that seemed to affect significantly were further analyzed until conclusions could be done about the influence.

The factors that were varied when simulating different running strategies were;

- The batch size for the injection molding
- The time interval between tool-change decisions
- The operation time for the water jet machines (see Section *5.1.1*)
- The distribution of the weekly required operation times for each machine

Two different options for each factor were used, and combinations of them were constructed (DOE) resulting in 16 different cases. The two options for each factor were:

- The two options for the batch size were either the proposed size by IAC or a doubled one.
- The time interval for tool-change decisions were varied between 4 and 6 hours.

- The operation time for the water jet machines were varied between 14 and 16 hours.
- The operation time distribution was either according to Figure 23, or to Figure 24.

The response for this analysis was the average consumption per produced product.

4.3 Plant layout

This part describes the process of evaluating the layout proposed by IAC and generate own proposals and compare them to each other.

4.3.1 Create proposals for the layout on the floor level

The layout review was restricted to a specific area of the plant. Also some of the machines were not practically possible to move and had to be considered as fixed. Only the floor level was considered and therefore the conveyor and the buffers were not considered. However the pick and place stations for the conveyor had to be considered. Creating different proposals for the layout was done using the steps mentioned in the SSLP method. The first step was to define the equipment. The next step was to construct the relation matrix (Appendix A) and defining the functional requirements of each resource (Appendix A).

4.3.2 Compare the proposals with IAC's proposal

A demonstration of the proposed layout by IAC was given in order to understand their concept and eventually find some pitfalls. It was important to find out what criteria that was important to take into consideration when evaluating the concept. A literature research was done in order to find out those criteria. The chosen criteria are shown in Table 3.

Table 3 – Chosen evaluation criteria for the layout.

No.	Factors	Weigh
1	Structured flow (few directions changes)	5
2	Social climate (ability to communicate, see each other, away from forklifts roads)	8
3	Availability for tool change	8
4	Scrap material handling	7
6	Space utilization (how much space can be used for other things)	5
7	Material handling (operators walking distances)	10

The reason behind setting the weights as Table 3 shows was due to the expected needs of IAC. The material handling factor take the highest weight as there is a need in IAC to utilize the operators more efficient by assign them on different tasks on different machines to cope with the demand variability. So it is good to have the different processes as close as possible.

When the concepts were developed, they were put into an evaluation matrix together with the IAC's proposal. Grades were put on each concept and criteria, and a final grade could be calculated for each concept (according to SSLP).

The two concepts with the highest grades were picked out and more detailed models of them were created. These concepts were presented for the company.

5 Results and analysis

This chapter introduces the results from this study regarding the three different topics; production flow dynamics, energy consumption and plant layout. Under each topic, the results from each question introduced in Section *1.5* are presented.

5.1 Production flow dynamics

In this section, the results of the questions in the production flow dynamics topic are presented.

5.1.1 What are the required operation times for the different machines?

When the iterative process described in Section *4.1.2* was performed, the minimum required operation times for each machine or department could be decided. The result of this can be seen in Table 4.

Table 4 – Resulting operation times for each department.

Department	Operation hours per day
Injection molding	19.4
Foaming (including F.T. and S.P.)*	16 / 10.9
Milling	14
Water jet	14
Laser (including Welding)	20.3

** F.T. means Flame treatment and S.P. means Skin preparation*

The numbers presented in Table 4 are excluding any stops for breaks. However, it includes time for breakdowns, disturbances etc. (in terms of OEE).The reason for having two numbers for the foaming department is that one of the product families is forecasted to be sold in higher amounts than the other. Since the two product families will use one foaming machine each, the required operation times are different for the two machines. 16 hours/day are required for the machine that serves product family 2 and 10.9 hours/day are required for the machine that serves product family 1.

It seems like the laser department is the system's bottleneck since it needs to be run for longest time in order to fulfill the demand. The foaming machine for product family 1 will be the less utilized machine since it only needs to be run for approximately 11 hours per day.

It could be seen that several combinations of operation times could achieve the requirements for the system; stable buffer levels and no overproduction. For example the operation time for the milling and the water jet machines could be increased without resulting in overproduction. By increasing the operation time for the water jet machines from 14 to 16 hours/day, a smaller maximum buffer level are achieved after the foaming department. However, the utilization of those machines decreased in that case since they had starvation some times.

The numbers in Table 4 are the minimum times that can fulfill the requirements. With those numbers, the buffer level for finished products is varying as Figure 14 shows, during a simulation of 30 days.

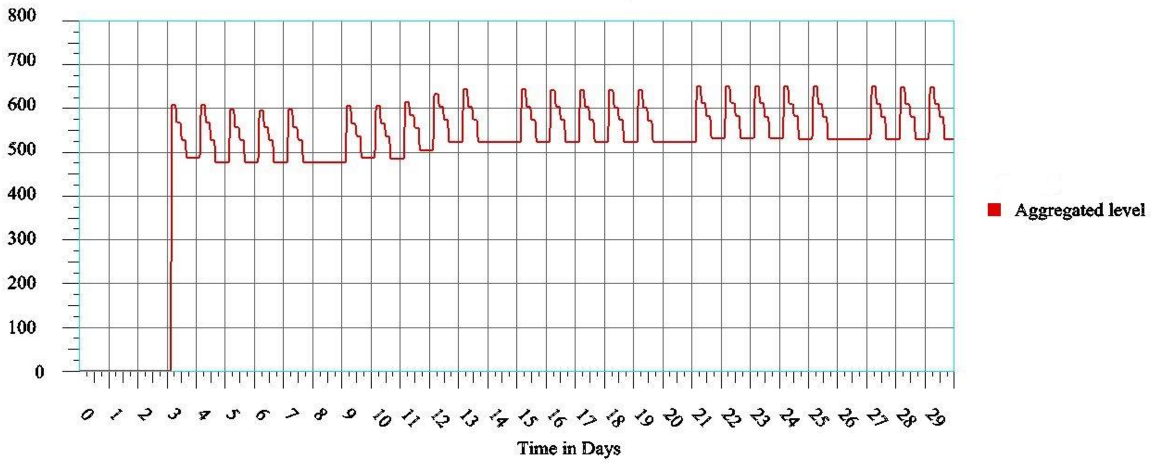


Figure 14 – Finished products buffer level.

The level for each variant in the buffer for finished products can be seen in Appendix B. It can be seen that the buffer levels are stable and that there is mostly no shortages of any variants.

5.1.2 What are the sufficient buffer capacities between the different processes?

The production system consists of mainly three internal buffers and one finished products buffer. The finished products buffer already exists and the capacity of it is thereby already set. However the needed capacities of the three internal buffers were investigated and the result is presented here.

The results presented regarding the buffer levels are under the condition that the operation times in Table 4 are followed each day from Monday to Friday.

Buffer after Injection molding

By studying the graphs generated for each product variant's buffer level in the buffer after the injection molding was found. The maximum buffer level when looking at all variants aggregated, as well as the maximum level for each variant individually can be seen in Table 5.

Table 5 – Maximum level for the buffer after injection molding.

Product variant	Maximum buffer level
1.1	800
1.2	200
2.1	800
2.2	300
Total	**2100**
Aggregated	**1400**

When the startup values for each product variant was adjusted so that each variant had some margin from shortage, the graph showing the buffer level of each product variant during a simulation of 30 days looks as shown in Figure 15.

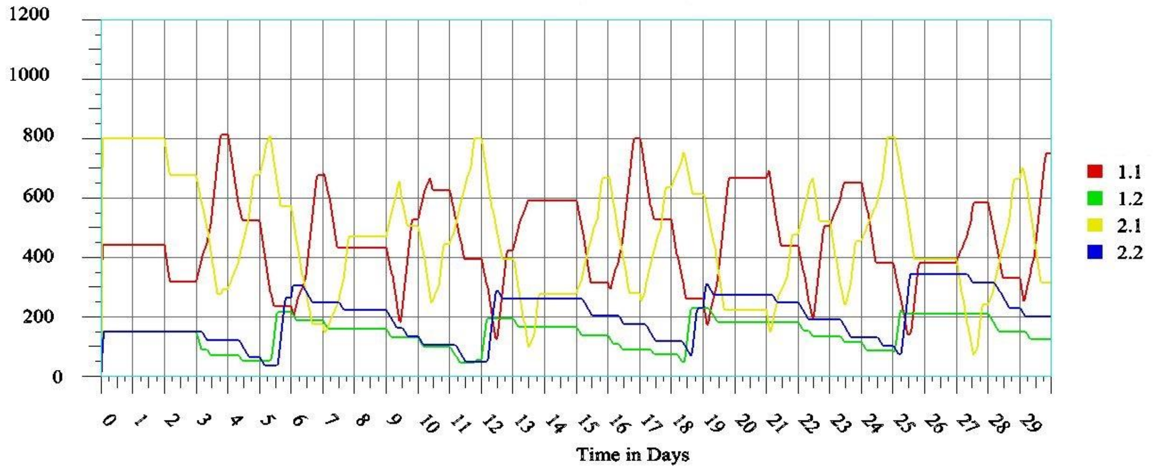


Figure 15 – levels for the variants in the buffer after injection molding.

The peaks in the beginning of the simulation are due to the initial creation of the startup values for each variant. The warm-up time for the simulation is 3 days. It can be seen that there are some safety levels for each variant between shortage and the lowest level. The *high runners* have somewhat higher safety levels than the *low runners.* When studying the aggregated level for the buffer, the graph for the same simulation looks as Figure 16 shows.

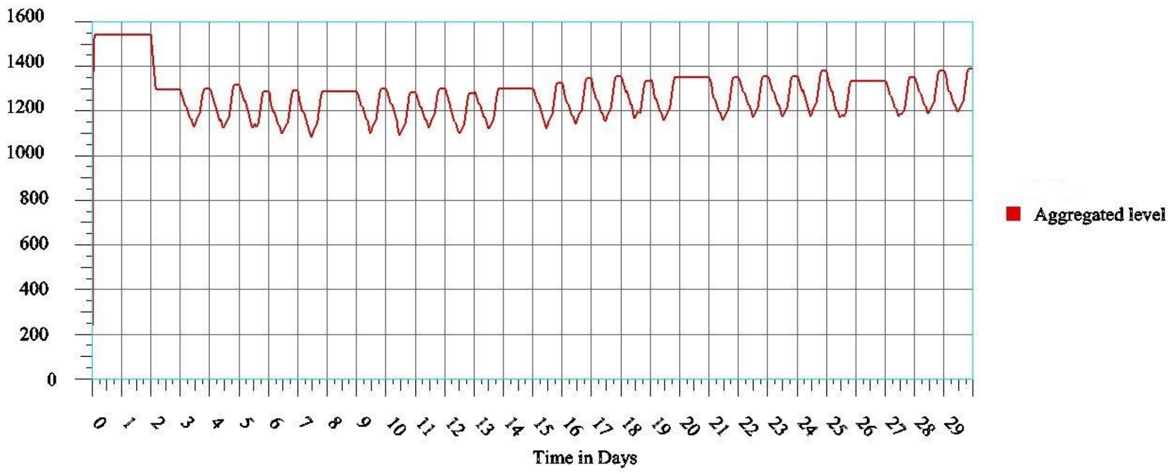


Figure 16 – An aggregated level for the buffer after injection molding.

In Figure 16 it can be seen that the total number of products in the buffer are fluctuating between approximately 1100 and 1400 products.

In order to decide the maximum buffer capacity, the required minimum safety stock for each variant must be decided. The numbers in Table 5 are suitable when using the safety stocks shown in Figure 15.

Buffer after foaming

The buffer after the foaming machines is mostly aimed to handle the products during curing. But also it store products coming from the foaming when the water jet or the milling machines does not working. During the simulation of 30 days, the aggregated level of the buffer looks as Figure 17 shows when using the operation time presented in Table 4.

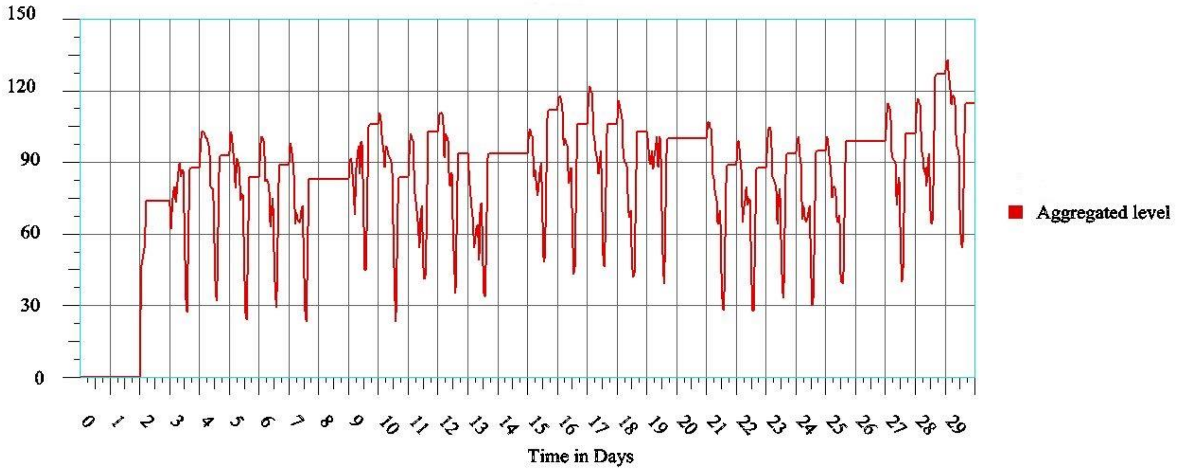


Figure 17 – An aggregated level for the buffer after the foaming.

Unlike the other two internal buffers, the buffer after the foaming is a first in- first out (FIFO) buffer. That means that the variants that are in the buffer will be controlled by the sequence that he foaming machines are producing with. Therefore, the variants are not needed to be studied for this buffer. The aggregated level of the buffer is reaching approximately 130 products as maximum. The level for this buffer is also dependent on the startup value. If a safety stock of minimum approximately 30 products, a buffer capacity of 130 should be enough according to Figure 17.

As mentioned under the result for the operation times (Section *5.1.1*), the buffer level for the buffer after the foaming are lower if the water jet machines are running for 16 hours/day instead of 14. For the case when the water jets are running 16 hours/day, the buffer level during the simulation looks as Figure 18 shows.

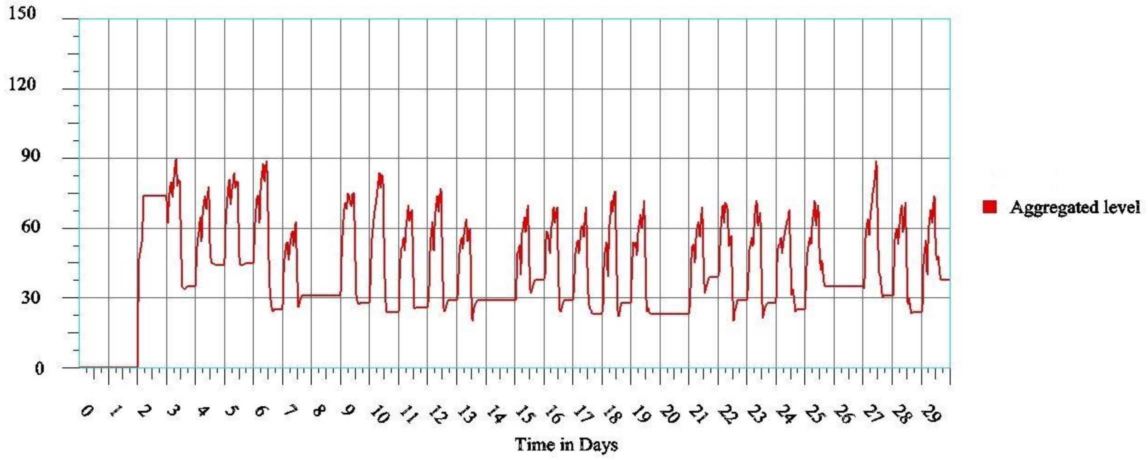


Figure 18 – Aggregated buffer level using 16 hours/day operation time for the water jet

It can be seen that the maximum level is approximately 90 products which means that the minimum buffer capacity should be 90 according to Figure 18. The minimum safety stock is still approximately 30 products. The reason for the smaller amplitude of the fluctuations is that the operation time for the water jet machines and the foaming machine for product family 2 are similar. When the water jet machines are running for 14 hours, there are 2 hours when the foaming machine is working and the water jet machines are not. Then the products coming from the foaming machine must be stored.

Buffer after the water jet and milling machines

When studying the graphs for each variant in the buffer after the water jet and the milling machines, the maximum levels for each variant and the aggregated level could be found. Those can be seen in Table 6.

Table 6 - Maximum level for the buffer after water jet and milling machines.

Product variant	Maximum buffer level
1.1.1	275
1.1.2	70
1.2.1	55
1.2.2	35
2.1.1	250
2.1.2	90
2.2.1	65
2.2.2	50
Total	**890**
Aggregated	**625**

This buffer is storing products that come from two different flows. However the machines downstream of this buffer can only process one of those flows at one time due to tool configurations in the machines. Therefore it is important that the products that fit to the downstream machines tool configuration are available on the right time. Similarly to the buffer after the injection molding, there is a demand that all variants should be available at all times. With the safety margins according to Figure 19 - 21, the minimum buffer capacities for each variant are as Table 6 shows. Depending on if there will be individual buffers for each variant or not, the buffer capacity must be designed either according to each variant's maximum level or the aggregated level.

In order to make it clearer to watch the buffer level for each variant, the variants were divided into three graphs (in total there are 8 different variants stored in this buffer). The levels for the two *high runners* can be seen in Figure 19.

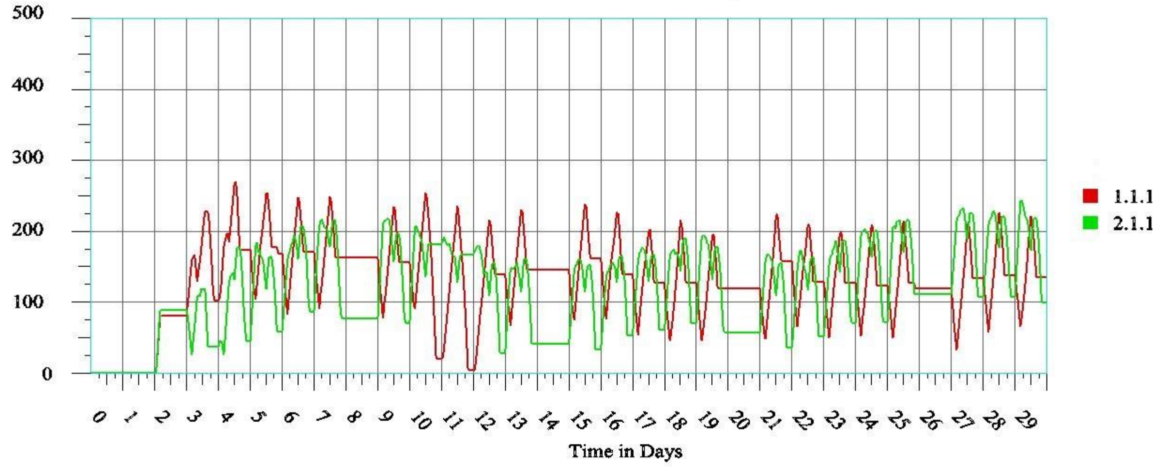


Figure 19 – The level of high runners in the buffer after water jet and milling machines.

The *low runners* of product family 1 can be seen in Figure 20.

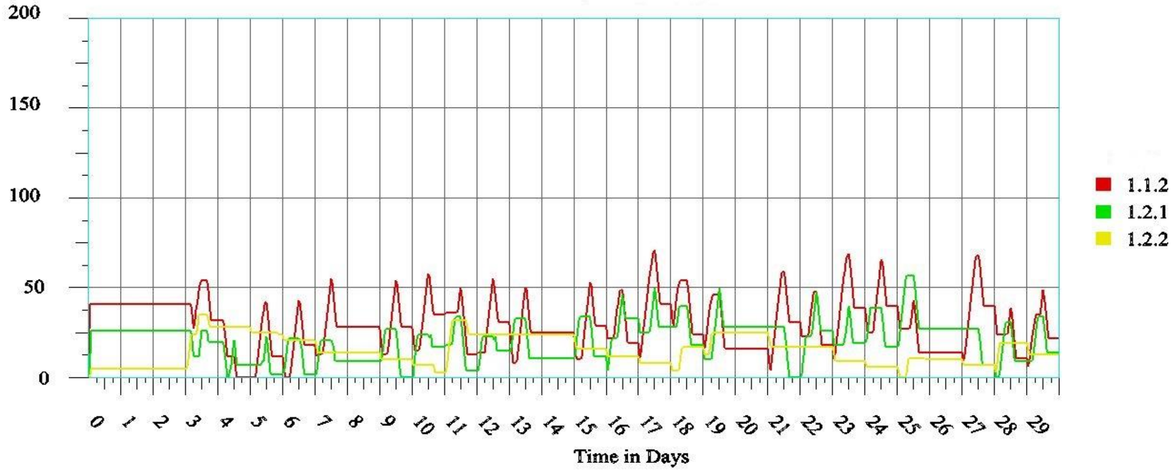


Figure 20 - The level of low runners of product family 1 in the buffer after water jet and milling machines.

The *low runners* of product family 2 can be seen in Figure 21.

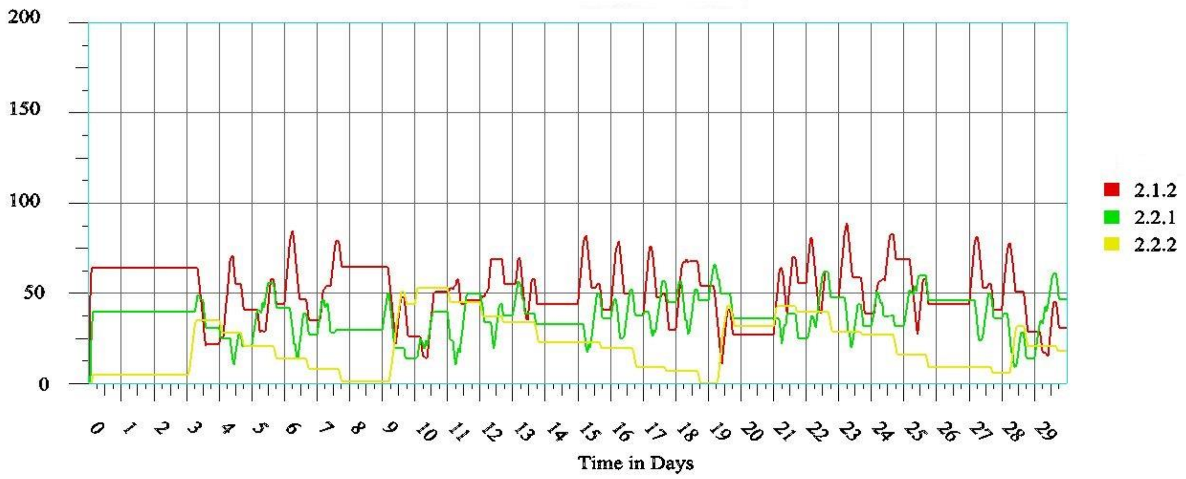


Figure 21 - The level of low runners of product family 2 in the buffer after water jet and milling machines.

In Figure 22 the aggregated buffer level can be seen. The level is fluctuating between approximately 350 and 625.

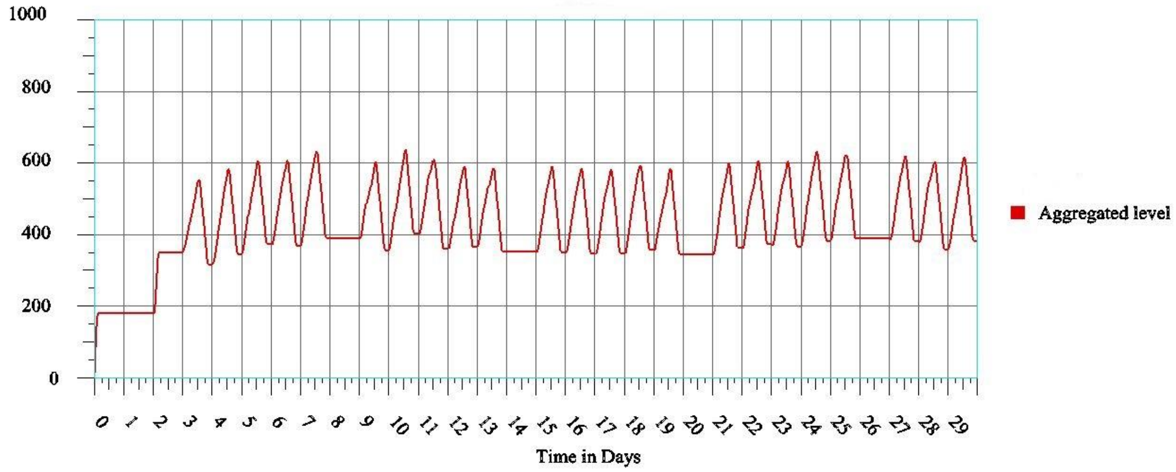
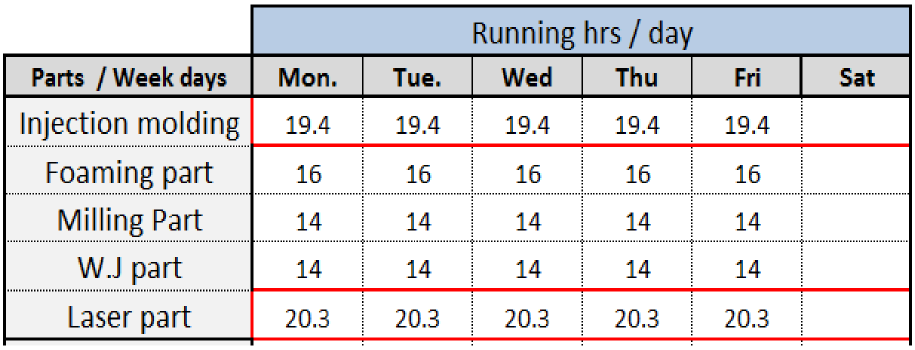


Figure 22 – Aggregated level for the buffer after water jet and milling machines.

5.1.3 Which production schedules can achieve a stable production?

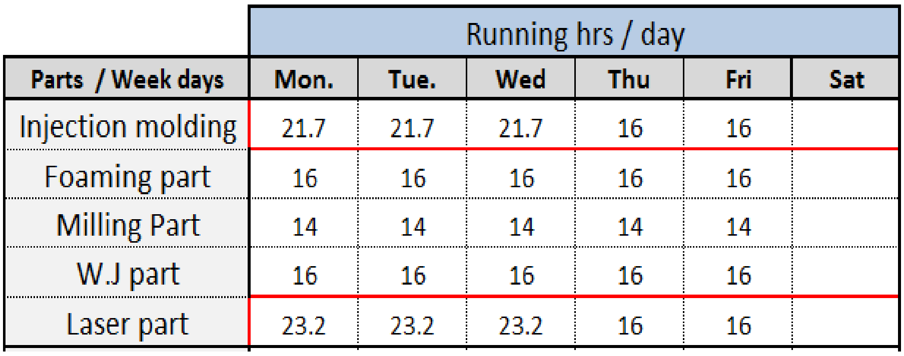
The obtained running times in Table 4, results in a production schedule as Figure 23 shows if using the same times each week day. That schedule achieves a stable production since both the finished IP buffer and the internal buffers are stable.



	Running hrs / day					
Parts / Week days	**Mon.**	**Tue.**	**Wed**	**Thu**	**Fri**	**Sat**
Injection molding	19.4	19.4	19.4	19.4	19.4	
Foaming part	16	16	16	16	16	
Milling Part	14	14	14	14	14	
W.J part	14	14	14	14	14	
Laser part	20.3	20.3	20.3	20.3	20.3	

Figure 23 – Production schedule using the obtained operation times in Table 4.

In Figure 24, a schedule where the weekly operation times for the injection molding and the laser department was redistributed to fit better into normal shift times. That schedule could meet the requirement of long term stable buffer levels.



	Running hrs / day					
Parts / Week days	**Mon.**	**Tue.**	**Wed**	**Thu**	**Fri**	**Sat**
Injection molding	21.7	21.7	21.7	16	16	
Foaming part	16	16	16	16	16	
Milling Part	14	14	14	14	14	
W.J part	16	16	16	16	16	
Laser part	23.2	23.2	23.2	16	16	

Figure 24 – Production schedule using distributed operation times over the week.

When using the production schedule in Figure 24, the finished IP buffer level looks as Figure 25 shows. The level is fluctuating significantly. The maximum level reaches around 750 which is over the available capacity. Also the safety stock is decreasing during the Thursday and Friday which means that the system would be more sensitive for longer disturbances in the end and in the beginning of the week than in the middle of it.

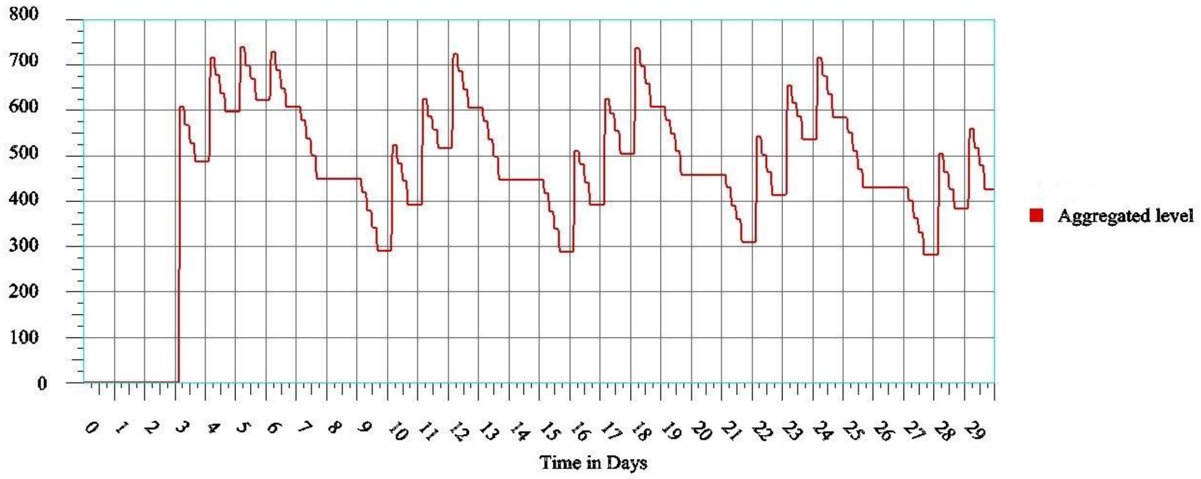


Figure 25 – Aggregated level for finished product buffer.

5.1.4 Is there a need for an additional third milling machine?

When simulating the system with two milling machines, the required operating time was 14 hours/day. When using three machines, the required operation time became mostly the same. The big difference was that the utilization went down significantly when using three machines and they had more starvation than when using two. This means that there is no need for a third milling machine.

5.1.5 Is it possible to reduce the no. of water jet machines from 2 to 1?

When the operation times in Table 4 and only one water machines were used, the finished IP buffer level looked like Figure 26 shows. That means that the system is not stable when only using one water jet machine and the operation times in Table 4.

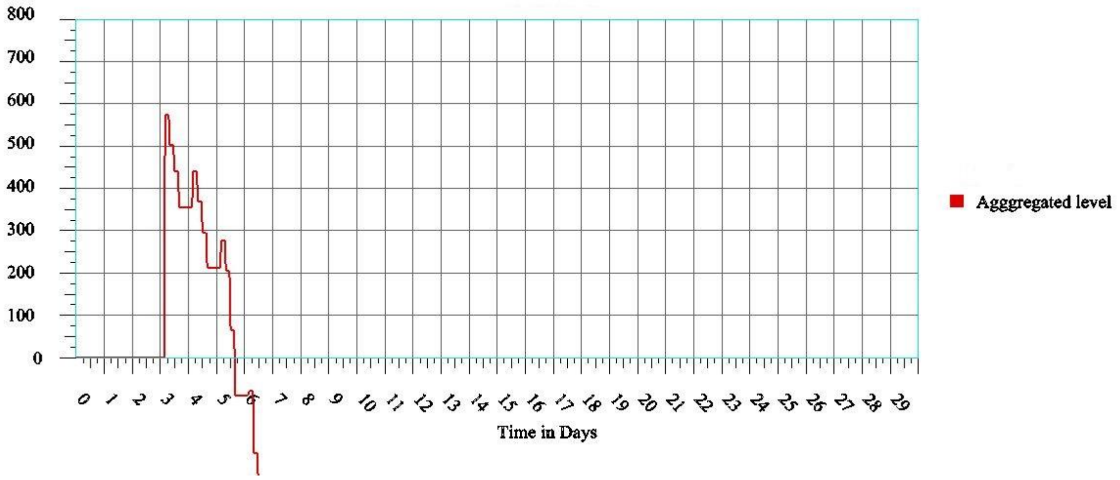


Figure 26 - Aggregated level for finished IP buffer using 1 water jet machine and operation time in table 4.

When the operation time for the water jet machines was maximized (that means 24 hours /day), the finished IP buffer level became as Figure 27 shows.

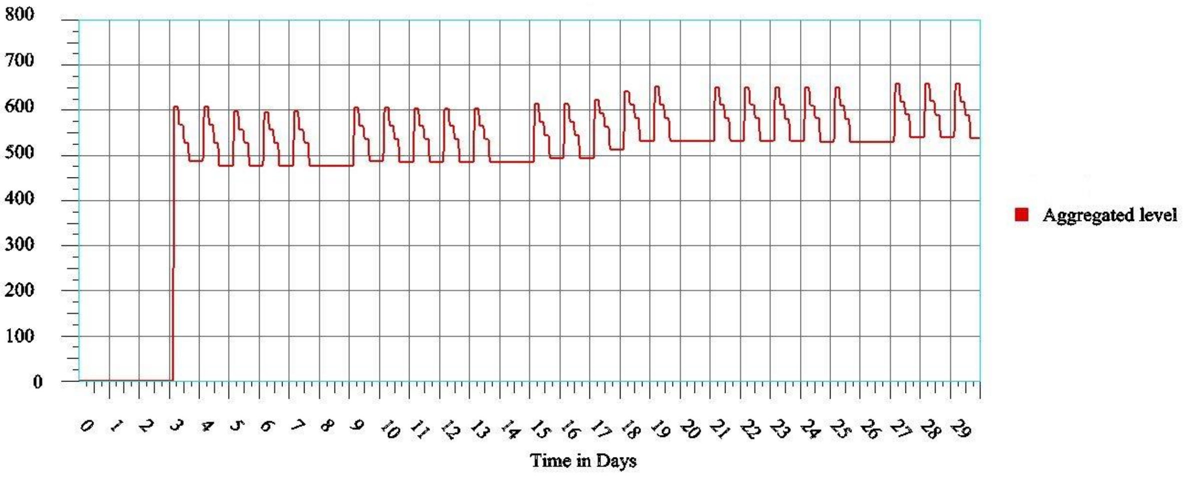


Figure 27 - Aggregated level for finished IP buffer using 1 water jet machine with operation time 24 hours/day .

The finished IP buffer level can be considered as stable. By checking the graph of the buffer after the cutting department, it could be stated that the water jet produced a suitable amount. However, using only one water jet machine results in larger buffer levels for both the buffer before the cutting department due to blockage and after the cutting department because it continue working after the laser department is closed.

According to the simulation, one water jet machine could be reduced if the operation time is set to 24 hour/day without breaks.

5.1.6 Will the system be able to endure higher customer demands than forecasted?

When the yearly customer demand was increased to 200 000 products annually, the operation times for each machine was increased as well in order to increase the output. When the laser department's operation time was 24 hours/day, and the other machines adjusted to that, the finished IP buffer level became as Figure 28 shows.

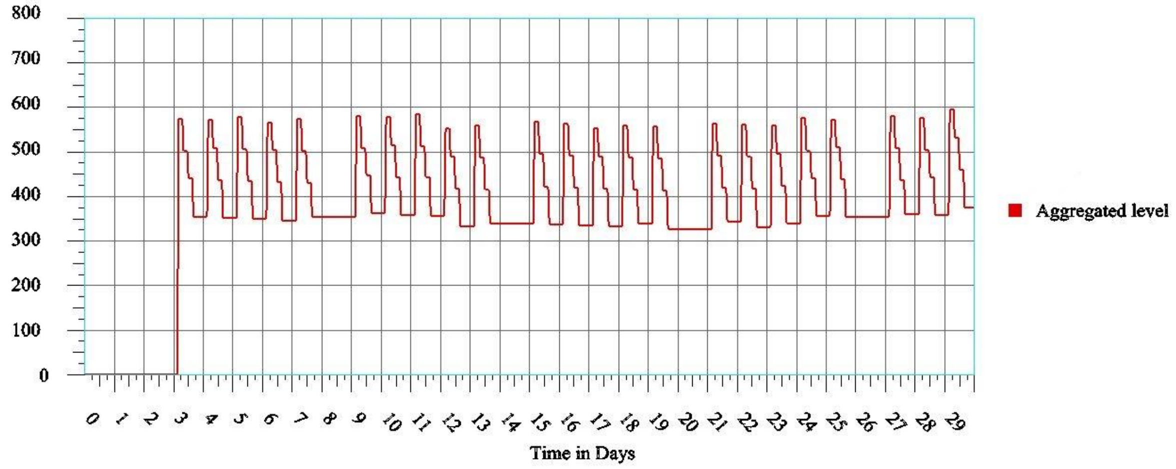


Figure 28 – Aggregated level for finished IP buffer under 200 000 products yearly demand.

It can be seen that the system can fulfill a yearly demand if running the laser department 24 hours/day (without any breaks). Suitable operation times for the other machines in this case are: injection molding- 23 hours/day, foaming- 19 / 12.9 hours/day, milling- 16 hours/day and water jet- 18 hours/day.

5.2 Energy consumption

This section presents the results from the energy consumption topic of this project. It starts by presenting the result of the energy mapping, and ends with the result from trying different running strategies.

5.2.1 How big is the energy consumption for each machine in the line at different states?

Each machine in the system was measured during some different machine states. Some machines had more significantly differences in energy consumption between different states than others.

From the gathered data, average numbers for each machine state and for each machine was calculated. Some states were not possible to measure. In those cases, estimations were done based on expert's opinions. All calculated numbers for each machine can be seen in Table 7.

Table 7 – Machines energy consumption at the different states.

	Consumption at State [kW] (per machine)					
	Machine warm-up	Processing	Idle	Tool-change	Tool pre-heating (before tool-change)	Standby
Injection molding	80	223		18.7	18	▨
Foaming (Including pre heating oven)	18.9	43	41.35	41.35	7.1	0.62
Water jet (including cleaning, crasher and water pump)	▨	58.41	58.41	▨	▨	2.48
Milling	▨	3.9	2.3	2.3	▨	1.24
Laser	▨	14.9	16.3	16.3	▨	0.62

The dark grey cells in Table 7 mean that the state did not exist for that specific machine.

Some machines had supporting equipment such as scrap crashers, washers etc. In Table 7 those supporting functions' consumptions are included in the main machine. For example the water jet machines had several such functions. Only functions that were directly linked to the machines in the studied production system were included. That means that for example overheads as ventilation and light was not included.

The graphs generated during the measurement for all machines can be seen in Appendix C.

The flame treatment, the US welding and the IR welding should been included in the study. Since those machines did not exist when the study was performed, they could not be included.

5.2.2 How big are the energy consumption and the CO2 emission for the whole line?

When the simulation of the energy performance was done, a summary of the result was done. The summarized data can be seen in Table 8.

Table 8– Summary of the energy consumption of the system.

	Daily consumption [kWh] (Average)	Daily CO_2 emissions [kg/day]	Consumption per product [kWh] (Average)	CO_2 per product [g/prod.]
Injection molding	4179	83.58	5.49	109.8
Foaming (x2)	1181	23.62	1.55	31
Milling (x2)	139	2.78	0.18	3.6
Water jet (x2)	1723	34.46	2.27	45.4
Laser	313	6.26	0.41	8.2
Total	**7535**	**150.7**	**9.91**	**198**

Note that the numbers for the foaming, milling and water jet machines are presented as the total consumption for both of each machine. The daily consumptions in Table 8 are calculated by taking the total consumption during the simulation, divided by the number of production days during the simulation. That means that stand by consumption etc. during weekends are added on the production days. The CO_2 emissions are calculated based on the statement that each kWh of electricity produced in Sweden emits 20 g CO_2 (Svenskenergi, 2013).

The consumption per product in Table 8 is an average value for all product variants. However, the product family 1 is using the milling machines while product family 2 is using the water jet machines instead. By looking at Figure 29, it can be seen that the average consumption per product, with the product families separated, differs significantly.

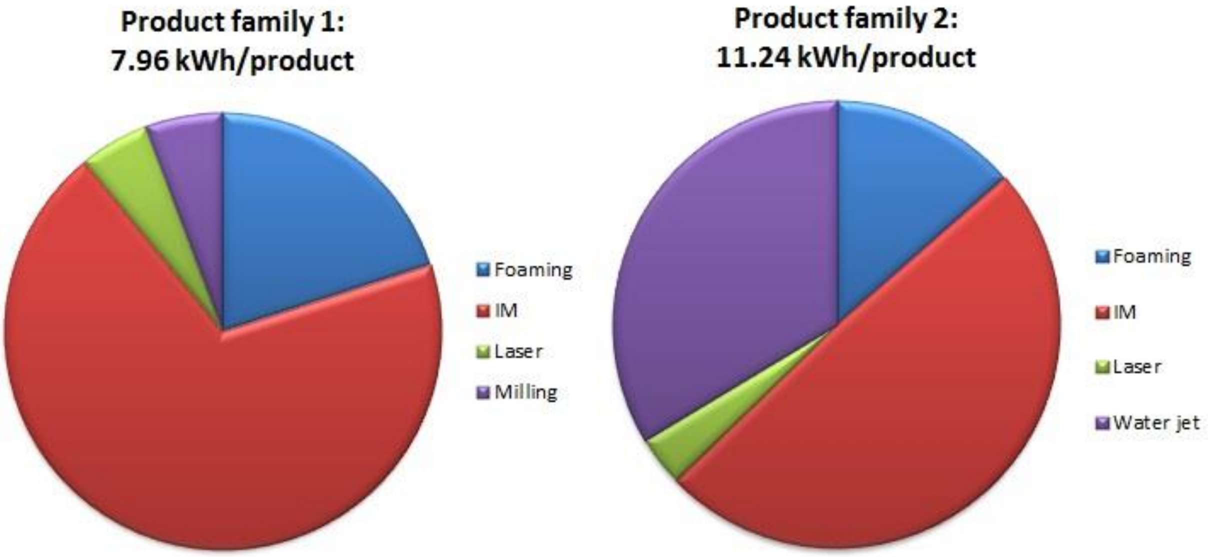


Figure 29 – Power consumption per product for each product family.

Also in Figure 29 it can be seen that for product family 1, the injection molding's consumption is the major, while for product family 2, the injection molding and the water jet machine's consumption are dominating together.

5.2.3 Can different production strategies (batch sizes, production schedules etc.) result in decreased energy consumption?

The full result of this analysis can be seen in Table 9. The yearly cost for the consumed energy and the energy cost per product are included. These calculations are based on the statement that 170 000 products in total will be produced yearly and the cost for 1 kWh is 0.7 SEK.

Table 9 – Different production strategies and their influence on the power consumption.

Case no.	Batch sizes	Waterjet time [hours/day]	Decision interval [hours]	Time distribution	Energy per product [kWh]	Yearly energy cost [SEK]
1	IAC	14	6	Figure 24	9.82	1168580
2	IAC	14	4	Figure 23	9.91	1179290
3	IACx2	14	6	Figure 24	9.92	1180888
4	IACx2	14	4	Figure 24	9.95	1184050
5	IACx2	14	6	Figure 23	9.97	1186113
6	IACx2	14	4	Figure 23	9.98	1187620
7	IAC	14	6	Figure 23	9.98	1187952
8	IAC	14	4	Figure 24	9.99	1188810
9	IAC	16	6	Figure 24	10.18	1211420
10	IACx2	16	6	Figure 24	10.21	1214990
11	IAC	16	4	Figure 23	10.25	1219750
12	IACx2	16	4	Figure 24	10.26	1220940
13	IAC	16	6	Figure 23	10.26	1220940
14	IACx2	16	6	Figure 23	10.26	1220940
15	IAC	16	4	Figure 24	10.27	1222130
16	IACx2	16	4	Figure 23	10.28	1223320

In Table 9, the results are ordered according to lowest cost, from top to down. It is clear that all cases, using 14 hours operation time for the water jet machines have the lowest costs. It can also be seen that the time distribution according to Figure 24 achieves the lower costs than according to Figure 23. The batch sizes and the decision interval for tool change seem to have small effect.

In Figure 30 the Pareto chart of the standardized effect of each factor can be seen. The Pareto chart confirms the observations from Table 9, since it shows that the operation time for the water jet machines have most significant effect on the energy consumption per product followed by the time distribution.

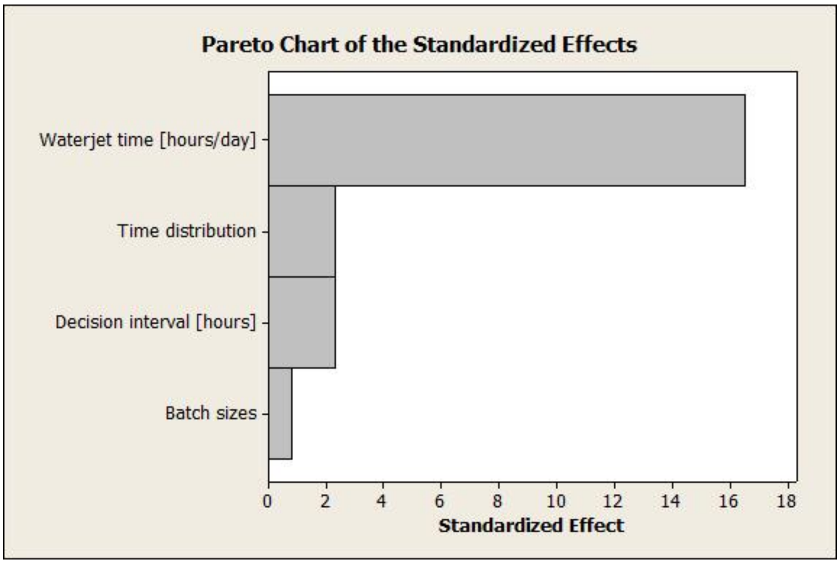


Figure 30 – Pareto chart for the standardized effect of each factor.

5.3 Plant layout

This part presents the result from the layout study. It presents different layouts generated by using SSLP and compares it with the proposal created by IAC.

5.3.1 Create proposals for the layout on the floor level

When following the procedure of SSLP and taking into consideration some important aspects, 7 layout concepts could be generated. All these concepts can be seen in Appendix D.

5.3.2 Compare the proposals with IAC's proposal

When comparing the proposals generated in Section *5.3.1* with IAC's proposal, the result became as Table 10 shows.

Table 10 – Evaluation matrix for IAC's proposal and own layout proposals.

No.	Factors	Weigh	IAC proposal	Layout 1	Layout 2	Layout 3	Layout 4	Layout 5	Layout 6	Layout 7
1	Structured flow (few directions changes)	5	O	O	O	U	A	E	I	U
2	Social climate (ability to communicate, see each other, away from forklifts roads)	8	A	I	U	O	O	E	A	A
3	Availability for tool change	8	A	I	I	E	A	E	E	A
4	Scrap material handling	7	A	A	A	A	A	A	A	E
6	Space utilization (how much space can be used for other things)	5	I	O	U	A	I	O	A	A
7	Material handling (operators walking distances)	10	E	E	I	E	E	I	E	E
	Scores		137	100	69	110	128	116	144	135

Where A = 4, E = 3, I = 2, O = 1, U = 0, X = -1

The factor's weights in table 10 are motivated in section *4.3.2.* In Table 10 it can be seen that one concept (layout 6) got higher grade than IAC's proposal. Layout concept 7 got a score close to IAC's proposal. Therefore, layout 6 and layout 7 were chosen to be further developed. These layout concepts were constructed in more details in 2D drawings.

The 2D drawing of IAC's proposal can be seen in Figure 31.

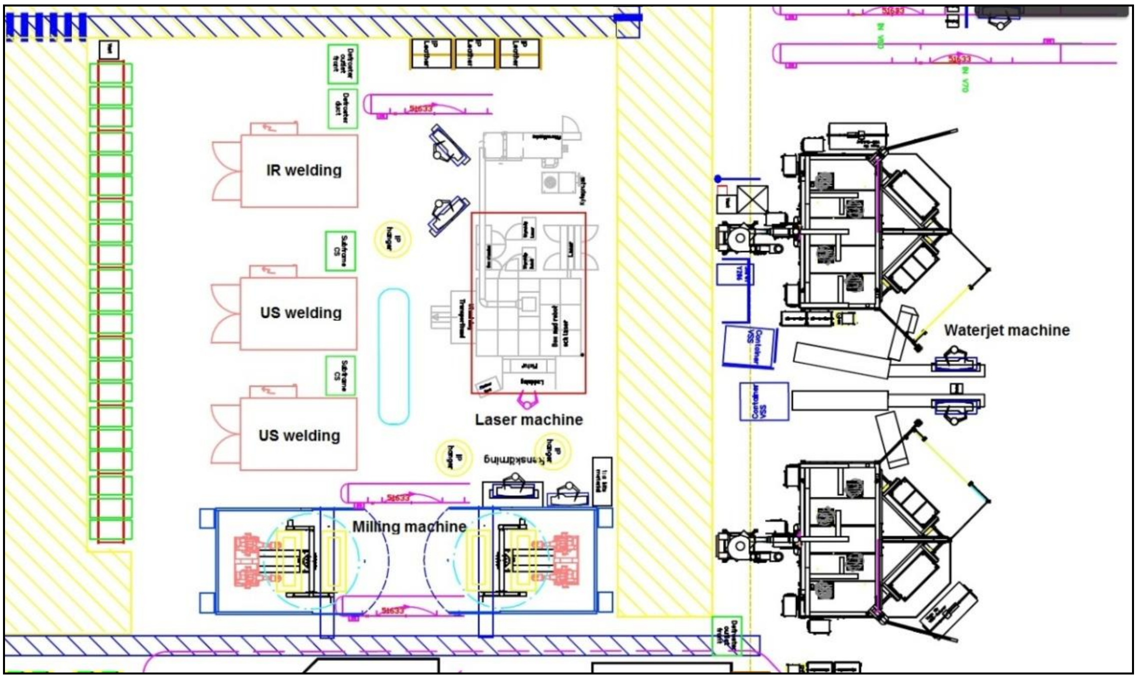


Figure 31 – IAC's layout proposal.

In Figure 32, the 2D drawing of layout 6 can be seen. The benefit of it compared to IAC's proposal is that the space is better utilized and there will be more space for other things. Also, according to the evaluation matrix, there is a more structured flow.

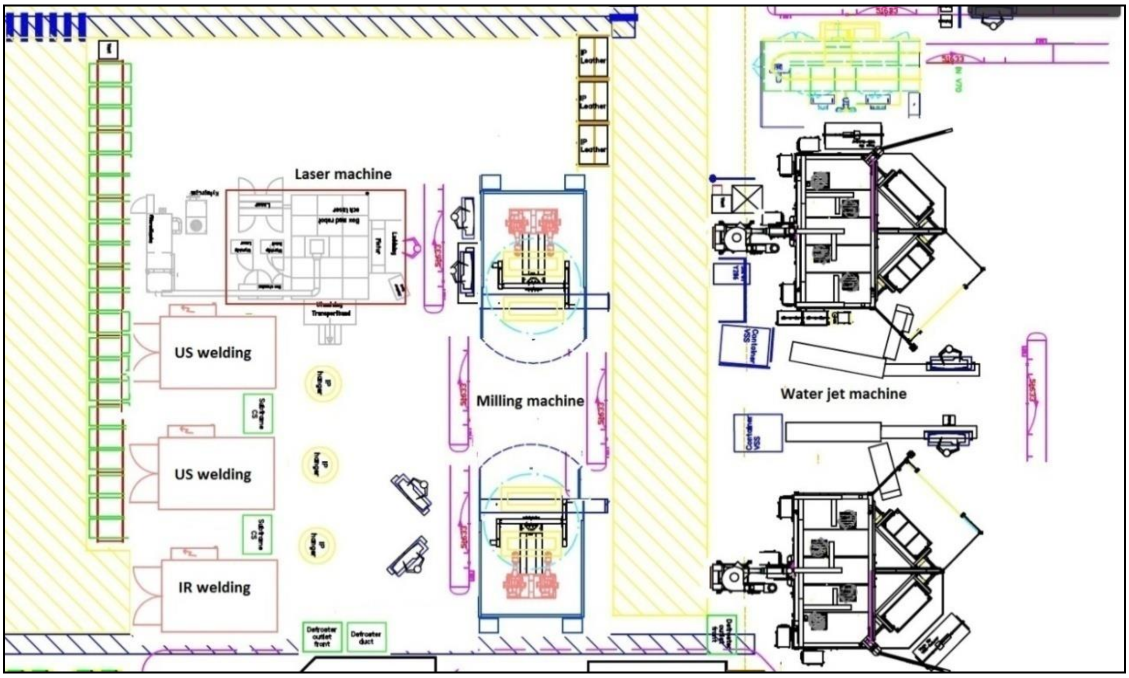


Figure 32 – Layout 6 proposal.

In Figure 33 layout 7 can be seen. The benefit of concept 7 compared to IAC's proposal is similar to concept 6 that the space is better utilized. The structured flow got a lower grade in the evaluation matrix (compared to concept 6) because it has more direction changes.

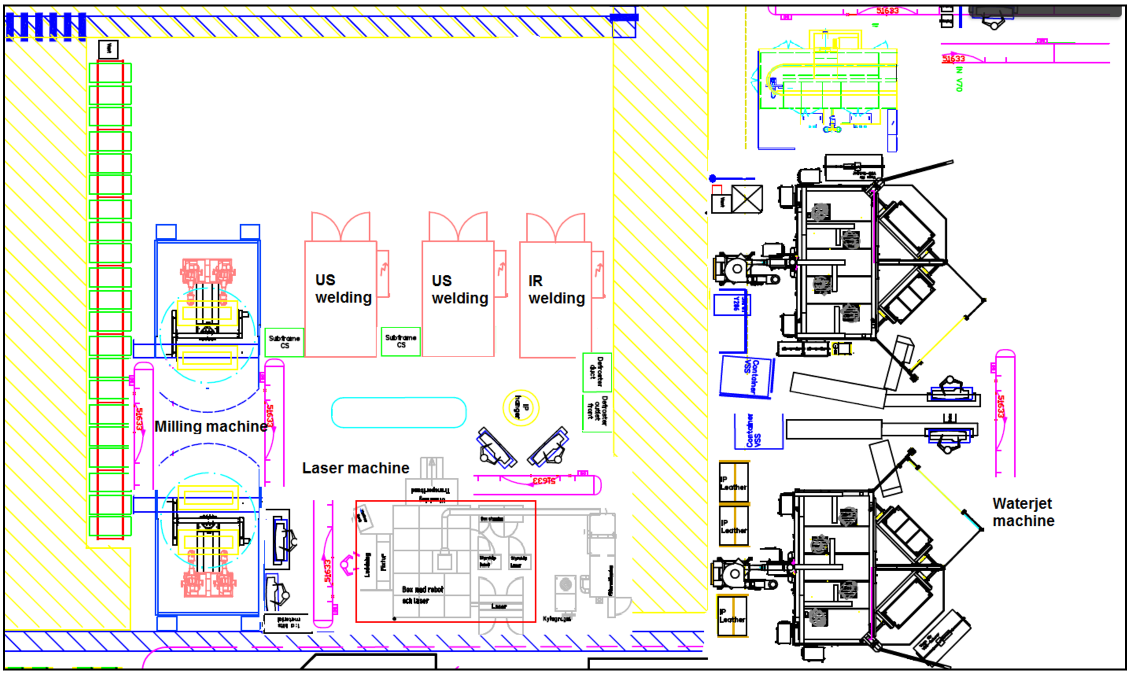


Figure 33 – Layout 7 proposal.

6 Discussion

In this chapter, discussions regarding the output of this project are discussed. It starts with a discussion section about the DES model, since that was used as a foundation for most of the generated result.

6.1 The DES model

This section discusses the point of strength and weakness for the DES model and evaluates the overall performance of the model and its reliability.

Machine breakdowns and scrape rate were represented in the model in terms of OEE. That results in a model with somewhat less dynamics than the reality probably will have. However it was decided that it was preferable to do that simplification instead of making rough assumptions for the breakdown times and the scrape rates. By expanding the cycle times according to the target OEE for each machine, the capacity of the system should be simulated in a reliable way. However, this simplification makes the reliability of the model lower than it should be if the breakdowns and the scrap rate should represented as in the reality.

The human tasks were not included in the model. Instead, cycle times for the machines were used under the prerequisite that the manning level is enough to serve the machines. The machines itself have fixed cycle times for each specific product variant, so if the operators are loading/unloading the machines on time, the cycle times should be close to fixed. Also, the plans for the production system were not that detailed when generating the model, so the human tasks were not possible to expect. In general, it was decided to not create more details than could be ensured to be reliable.

The model does not react as the reality will be especially when it comes to taking decisions and logics inside the system for tool change and product. It is not as flexible as the human decision will be when taking decisions to change products and tools based on the real situation. However some simple algorithms were used in the model to be able to mimic the human decision as good as possible.

6.2 Production flow dynamics

The results generated under the production flow dynamics were generated by using the DES model. As the previous section discussed the uncertainties of the model itself, this section discusses the result under the production flow dynamics that was generated using the DES model.

According to the simulation model, the machine operation times in Table 4 are enough, both for keeping stable internal and finished IP buffers. Those times are prerequisites that the customer demand is 170 000 products annually, are distributed as Figure 1 shows and are evenly distributed during the year.

The model is using the OEE values that IAC expects that they can fulfill for each machine. If the reality shows something else, the operation times in Table 4 will not be correct. Also the cycle times used in the simulation model have to be realized which can be partly dependent on the manning level. In general it can be said that the operation times in Table 4, should be trustable if the inputs used in the simulation model are correct. It is important to be aware of that the operation times are excluding any breaks. However, tool-changes are included and it could be a possibility to partly combine those with breaks.

Due to the estimations and simplifications in the model, both regarding logics and input data, the operation times can be used as an indication of how much time each machine needs to be run. The customer demand used is a forecasted number, which means that the reality will probably differ somewhat. That will of course result in other operation times than presented in Table 4. However, under the assumption of 170 000 yearly demand, the result from this simulation verifies that the system can fulfill that with some margin. The most critical machines are those in the laser department which needs to be run for approximately 20.3 hours/day, have 3.7 hours/day available for breaks.

When the required buffer capacities were studied, it was a critical question to decide the safety stock level in each buffer and for each variant. Since the different variants are forecasted to sell in different amounts, the needed safety stock will be different for each variant and buffer. The buffer capacities in Table 5 - 6 are the result after decreasing the stock level for each variant so that its minimum level has some margin to the shortage limit. If bigger minimum safety levels are desired for some variant, that extra level has to be added to the buffer capacities in Table 5 - 6.

When deciding the size of the buffers that will be built in the real production system, it is important to take into consideration some things that the model does not handle. First, it is important to ensure that a short machine breakdown does not affect the whole system. Therefore it is needed to have some extra capacity that can store products while the downstream machine is down. Also, if the upstream machine is down for a while, it is important that the downstream machine will not starve due to a short breakdown. Since the model does not have any breakdowns, it is hard to know if the buffer capacities in Table 5 - 6 can manage those problems.

Since the cycle times used in the model are longer than the real ones (due to the OEE compensation), there is also an uncertainty factor if that affects the required buffer capacities. If the machines are working faster, it is relevant to assume that the fluctuations in the buffers can be bigger which can result in higher required buffer capacities.

Due to the nature of the buffering system, where some variants will have separated conveyor buffer paths, there is an uncertainty of how to decide the buffer capacities. The buffers are constructed as circles as can be seen in Figure 7. The *high runners* will probably occupy several “circles” while some of the low runners probably will use some common. To decide the exact buffer capacities, it is required to know those combinations and the capacity of each “circle” which was not the case at the project time. However, Table 5 - 6 shows the maximum buffer levels for each variant. Those are good indications on how big the buffer needs to be. In order to generate more detailed information, a simulation should be done when it is decided which variants that will be combined.

The result obtained for the other questions under the production flow dynamics such as the need for two or three milling machines, using one water jet machine and the system respond towards increased customer demand is basically related to the model reliability and data handling in the model as it was mentioned above.

6.3 Energy consumption

This chapter discusses the results found in the energy consumption part of this project. It discusses the result from each of the questions of the topic.

The equipment used for measuring the power of the different machines was Powervisa by Dranetz (Dranetz, 2013). It is a sophisticated equipment and it gave the possibility of measuring the machine data in a reliable way. The simulation model did not include the energy consumption for the flame treatment and the welding machines since they did not exist when the data gathering was performed. Of course that is affecting the final result. Therefore, in order to get more realistic figures of the total consumptions, data for those machines have to be added.

For some machines, the same power curve could be seen repeated in all cycles. That means that the prerequisites of having a good statistical distribution were good. The data were decided to be represented as deterministic and due to the stability of the power curves, this was a suitable way to represent it. However, some machines had some variations from cycle to cycle, often because some auxiliary equipment of the machine worked independently on the machine state (for example cooling). These machines were also decided to be represented as deterministic data. In order to do that, it should have been suitable to have bigger sample sizes in order to calculate average values. Due to lack of time it was not possible to do those big samples. There is a possibility that the average numbers calculated from to small sample sizes can affect the result somewhat.

Some states were not possible to measure due to the long time span between those occurrences. By analyzing what parts of the machines that worked during the state that were not possible to measure, qualified estimations could be done since partly the same parts of the machine worked during states that were possible to measure. These estimations were done together with an electrician at the company. Even though the estimations probably are qualified, some deviations from the reality probably occurs which can affect the result.

Some assumptions are made for the energy aspect of the DES model. For example it assumed that all equipment is turned to standby as soon as the machine has been run for its planned operation time. Also, since the cycle times are longer in the model than in the reality (due to breakdown and scrap representation in terms of OEE), the processing consumption amount becomes higher than it should be. In reality, there will be some consumption for the breakdown states which is probably smaller than processing consumption which is not included in the model. For that reason, it is reasonable to say that the numbers from the simulation are slightly higher than they should be.

Overall, the machine measurement was successfully performed. It was noticed when studying the different processes that the auxiliary equipment for the machines were needed to be included in the measurement in order to make the result representative. There was a problem to combine that equipment with the machine states as this equipment is working mostly independent from the machines. However, those combinations were done and the final result should still be representative.

6.4 Plant layout

The reason behind choosing the different evaluation factors that are shown in Table 3 was the need to construct a sustainable layout that could be successful in achieving different goals such as operator satisfaction, economical profit, lean perspective etc. Comparing layouts 6 and 7 that got the highest scores; layout 6 shows that it is better in the flow structure and scrap material handling than layout 7. However layout 7 shows more ability regarding availability for tool change. Both layouts are much better than the layout proposed by IAC at the point that they utilize the space in much better way. The proposed layouts also provide a good social environment and communication for the operators because they get closer to each other. This provides an ethical work environment for the operators which contribute to a sustainable development (Figure 4). By having the operators close to each other also gives the opportunity to deploy the operators on several tasks on the various machines to utilize them in a good way. Even though the available data for studying the layout was not wide because of not having a decision for the design of the conveyors etc., the study should still be able to work with the current data for the machines and propose some different layouts.

7 Conclusions and Recommendations

This project has resulted in some conclusions that are useful to study for the construction phase of the coming production system at IAC. Also, it gives valuable information that can be useful when the system is up and running. In this chapter, those conclusions and recommendations related to the questions from the goals of this project (chapter *1.5*) are presented.

7.1 Production flow dynamics

This section presents the conclusions and recommendations for the questions studied under this topic.

What are the required operation times for the different machines?

The operation times proposed in Table 4 can be used as indications on how much time each machine needs to be run each day. Also it can be seen as verification that the machine setup will be enough to fulfill the forecasted customer demand.

What are the sufficient buffer capacities between the different processes?

As mentioned in the discussion chapter, there are some uncertainty factors for the required buffer capacities. However, it can be concluded that the capacities in Table 5 - 6, is a minimum of what is needed. In order to ensure flexibility in the system and some safety for disturbances, it is recommended to add some 10-20% of the capacities proposed in Table 5 - 6. Extra buffer capacity means more space requirement and some more investment. However it would be a safety against blockage etc.

Which production schedules can achieve a stable production?

It could be seen at the trial where the weekly running times were redistributed in order to be more suitable for normal shift times that the buffer levels became more fluctuating. The safety levels varied a lot during time and the maximum level for the finished IP level became higher than wanted. Therefore it is recommended to run the specific required operation time for each machine every week day. That will result more stable buffer and safety levels during time.

Is there a need for an additional third milling machine?

As the required operating time for the milling machines when using two machines was 14 hours/day, there is not a need for a third milling machine. Using three milling machines will only result in a lower utilization of all milling machines. Therefore it is recommended to not use a third machine.

Is it possible to reduce the no. of water jet machines from 2 to 1?

The simulation showed that by using one water jet machine and run it for 24 hours/day, the demand could be fulfilled. However, there is no time for breaks and there is no safety level at all. Also there will be bigger fluctuations in the buffer level after the foaming and the maximum level will be higher. Also the buffer level after the cutting department will be fluctuating more than when 2 machines are used. Due to all these reasons, it is not recommended to reduce one water jet machine. Instead, it is recommended to use 2.

Will the system be able to endure higher customer demands than forecasted?

When the yearly customer demand was set to 200 000, the laser department were needed to be run for 24 hours/day in order to fulfill the demand. That means that there is no time for breaks etc. and no safety time are available. Therefore it is reasonable to believe that a yearly demand of 200 000 can be hard to fulfill. However, demands close to 200 000 should be able to fulfill if overlap is applied breaks and the expected OEE can be fulfilled.

7.2 Energy consumption

How big is the energy consumption for each machine in the process at different states?

The consumption for each machine at different states can be seen in Table 7. It can be seen that the consumption for some machines are mostly the same during processing as during idle. A conclusion from that is the importance of utilize the machines as much as possible, otherwise energy will be consumed without generating any value for the company. Also the consumption during tool-changes at some machines is close to the processing consumption. This could be a reason for having as long intervals as possible between making tool changes.

When looking at the pie charts (Figure 29), it can be seen that product family 2 are consuming more energy per product than product family 1. That is only because of the usage of water jet machines instead of milling machines. The milling machines and the water jet machines are performing the same task; cut away excess material from earlier processes. If milling machines had been used instead of water jet machines also for product family 2, approximately 3.28 kWh per produced product of product family 2 could have been saved. Under the condition of 170 000 total yearly demand and 60% of those are product family 2, approximately 235 000 SEK could be saved annually in terms of energy costs.

How big are the energy consumption and the CO2 emissions for the whole process line?

The simulated energy consumption for the whole system became approximately 7500 kWh per day. That means 5250 SEK/day in pure electricity costs. It can be concluded that two of the machines; the injection molding was significantly the biggest consumer followed by the water jet and the foaming machines. The water jet machines are dependent on some auxiliary equipment that consumes high amounts of electricity. As mentioned in the previous section, money can be saved by using milling machines instead of water jet machines. Of course it is a big investment and maybe also some technical issues but it is recommended to make a further investigation of the benefits compared to the drawbacks.

When the machines were measured, it could be seen that some equipment were not switched off during breaks (such as scrap crashers etc.). It is recommended to investigate the routines for such cases. Probably, energy costs could be decreased by establishing strict routines for how to handle this.

Can different production strategies (batch sizes, production schedules etc.) result in decreased energy consumption?

The complete result of the running strategies trial can be seen in Table 9. It can be seen that all the configurations with 14 hours operation time for the water jet machines achieved the best result. The fact that the water jet machines' operation times seemed to influence the energy consumption most significantly, is also supported by looking at Figure 29. According to Section 5.1.2., the buffer level after the foaming can be kept at a lower level by increasing the operation time for the water jet machines. It seems to be a tradeoff that has to be done. Either using a longer operation time (around 16 hours) and keeping a lower buffer level after the foaming or using a shorter operation time (around 14 hours) and save energy costs. Also by using the longer operation time, the machine utilization of the water jet machines will be lower. For these reasons it is recommended to use the lower operation time (14 hours/day) for the water jet machine. According to Table 9, 0.34 kWh per product can be saved by using 14 hours instead of 16 (case 2 and 11). With a yearly demand of 170 000 products and an energy cost of 0.7 SEK/kWh, approximately 40 000 SEK should be saved annually by using the lower operation time for the water jet machines.

To vary the batch sizes for the injection molding turned out to not affecting the energy consumption mostly at all. The reason for that is probably that the proposed batch sizes from IAC are already big (the biggest around 2 production days). By making the batches even bigger, some single tool-change hour consumption can be reduced and the total operation time can therefore also be reduced. However, according to Figure 30, the effect seemed to be negligible. Therefore, it is recommended to use the planned batch sizes.

The case were the weekly running hours were redistributed in order to fit the normal shift times, seemed to have some effect on the energy consumption. However, according to Section 5.1.3., it is not suitable to run with this production schedule and the effect of it can therefore be neglected.

The time interval between the tool-changes (for foaming, milling, and laser) was varied between 4 and 6 hours. The effect of this factor turned out to be quite small. The expectation was that the tool-change intervals should have more influence on the energy consumption but probably the interval has to be increased quite significantly in order to influence more. However, increasing the interval too much will result in instability in the buffer levels for each variant. In the energy aspect, the decision interval turned out to be unimportant. However, in order to keep high machine utilization, it is recommended to strive for longer decision intervals.

It can be concluded that most of the factors that were evaluated did not result in significantly reduced energy consumption. However, the operation time for the water jet machines must be considered as influencing.

7.3 Plant layout

Create proposals for the layout on the floor level

7 layout concepts were generated, since the area that was available to play with was restricted; many of the concepts had big similarities with each other. Most of the concept turned out to be worse than IAC's proposal. However, two of them were promising and were chosen to be further developed.

Compare the proposals with IAC's proposal

The two layouts that got the highest scores were, according to the evaluation matrix, mostly as good as IAC's proposal. The benefit with the new proposals was mostly that space could be saved and used for other tasks. If it is valuable for IAC to use that space for other things, we recommend taking those new proposals into consideration.

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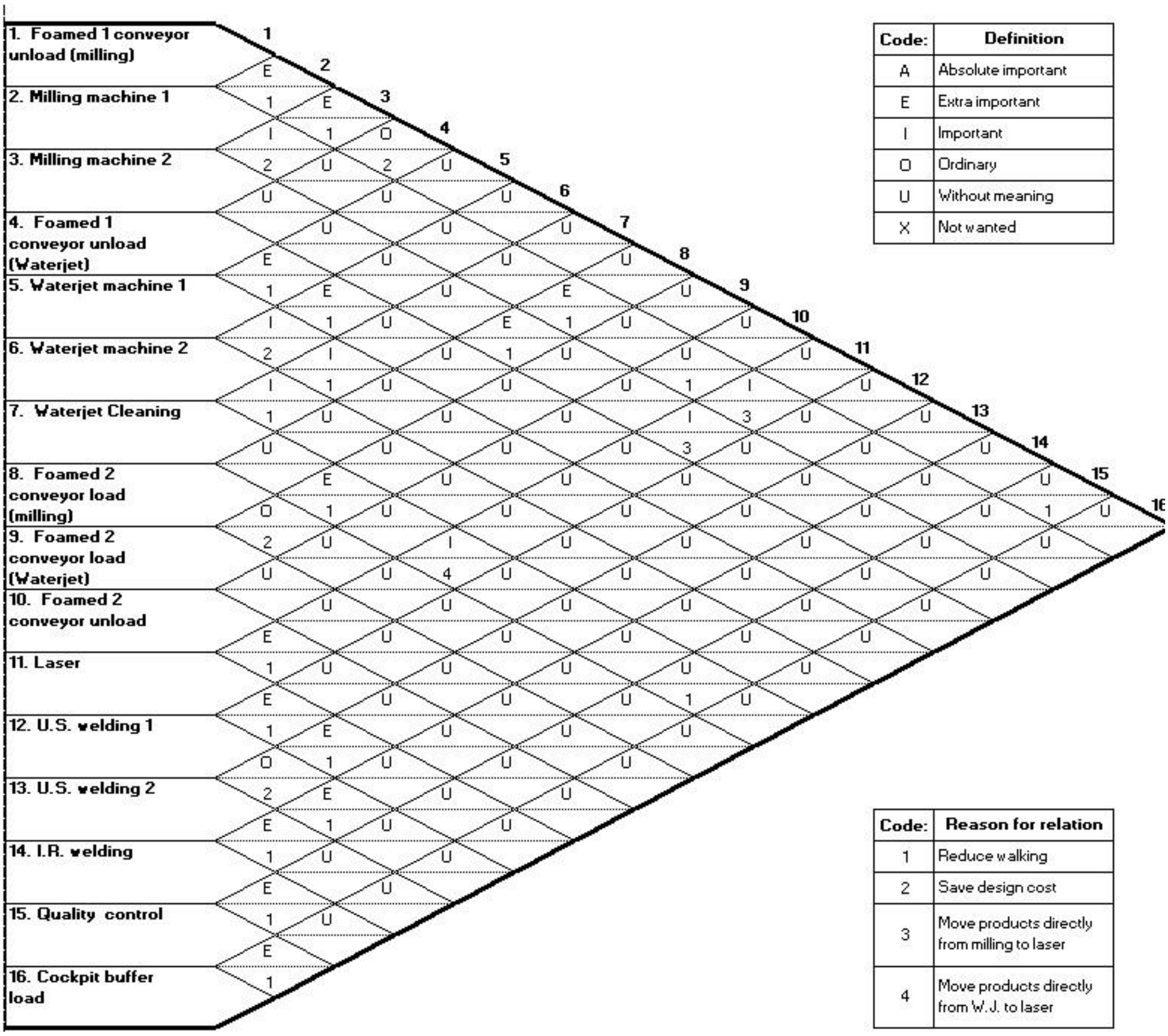
Appendix A

Relation diagram

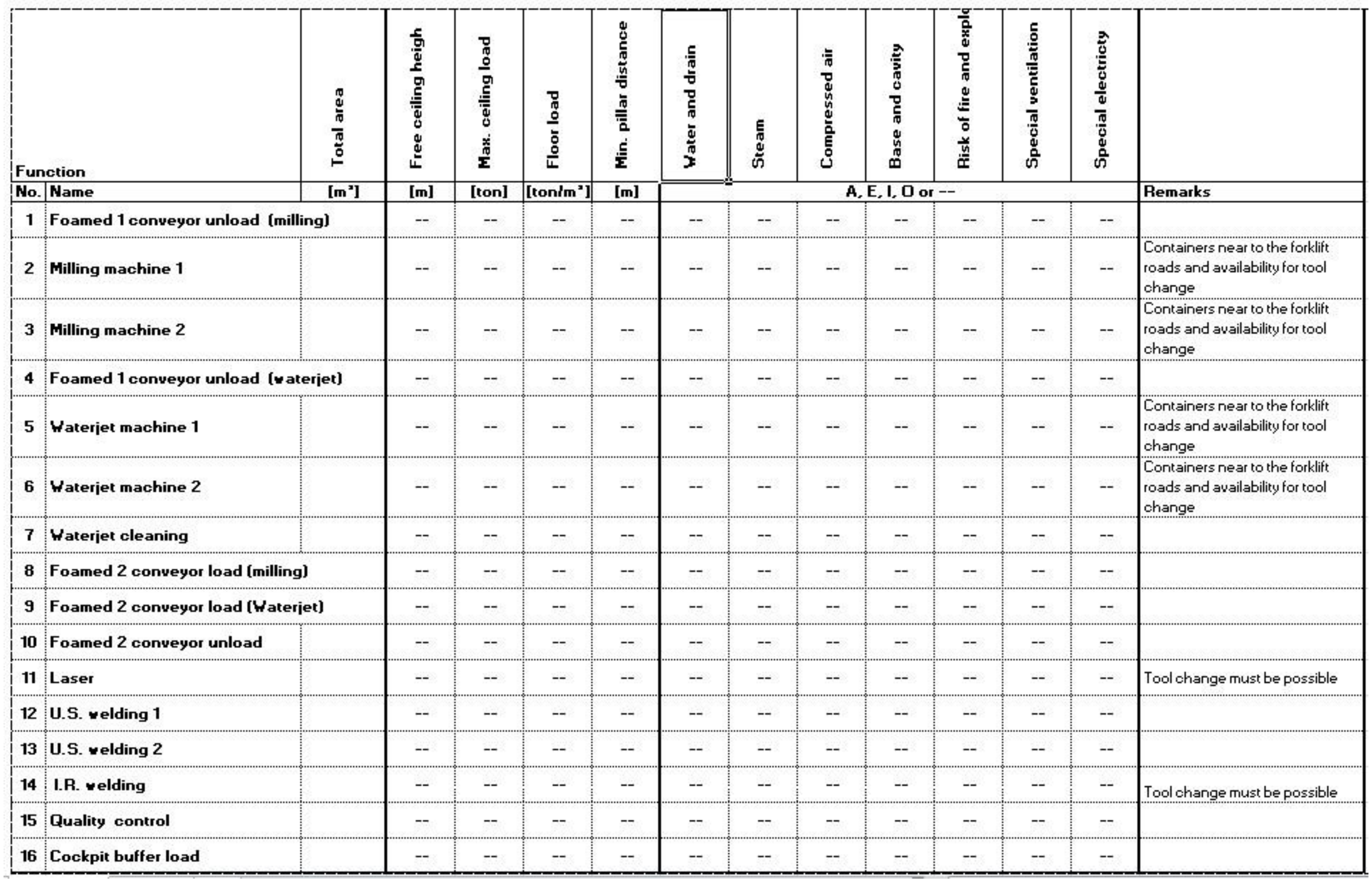


	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	E 1	E 1	O 2	U	U	U	U	U	U	U	U	U	U	U 1	U
2		I 2	U	U	U	U	E 1	U	U 1	I 3	U	U	U	U	U
3			U	U	U	U	E 1	U	U	I 3	U	U	U	U	U
4				E 1	E 1	U	U	U	U	U	U	U	U	U	U
5					I 2	I 1	U	U	U	U	U	U	U	U	U
6						I 1	U	U	U	U	U	U	U	U	U
7							U	E 1	U	I 4	U	U	U	U 1	U
8								O 2	U	U	U	U	U	U	U
9									U	U	U	U	U	U	U
10										E 1	U	U	U	U	U
11											E 1	E 1	U	U	U
12												O 2	E 1	U	U
13													E 1	U	U
14														E 1	U
15															E 1

Code:	Definition
A	Absolute important
E	Extra important
I	Important
O	Ordinary
U	Without meaning
X	Not wanted

Code:	Reason for relation
1	Reduce walking
2	Save design cost
3	Move products directly from milling to laser
4	Move products directly from W.J. to laser

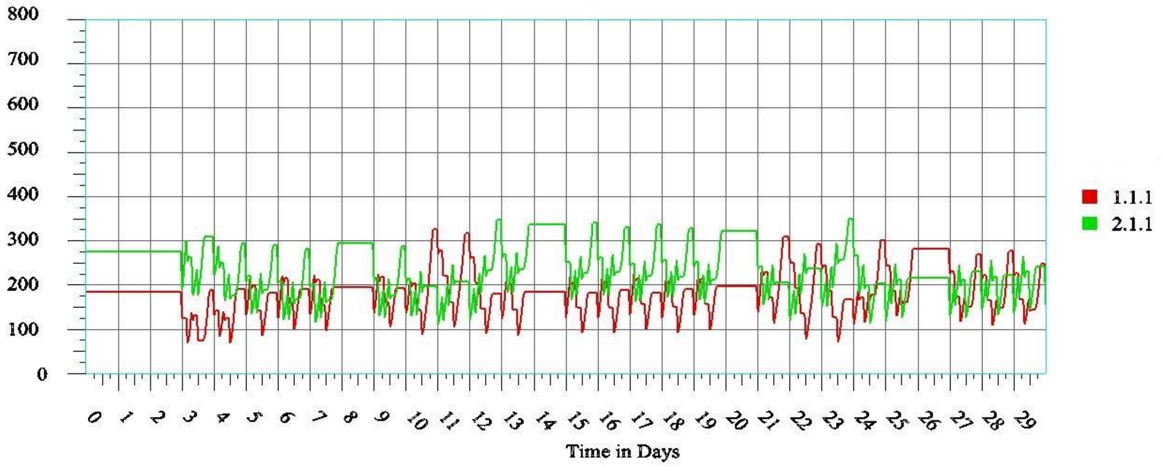
Functional requirements

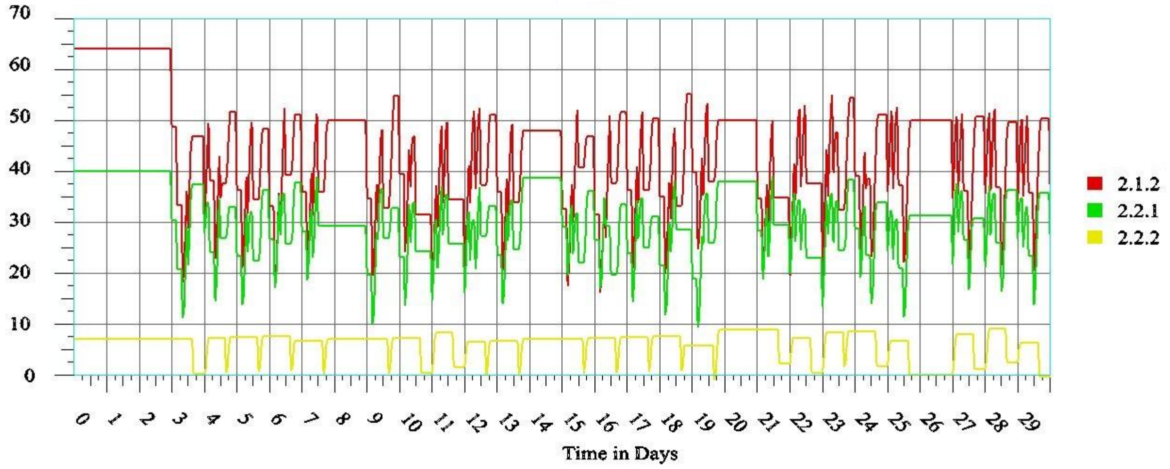


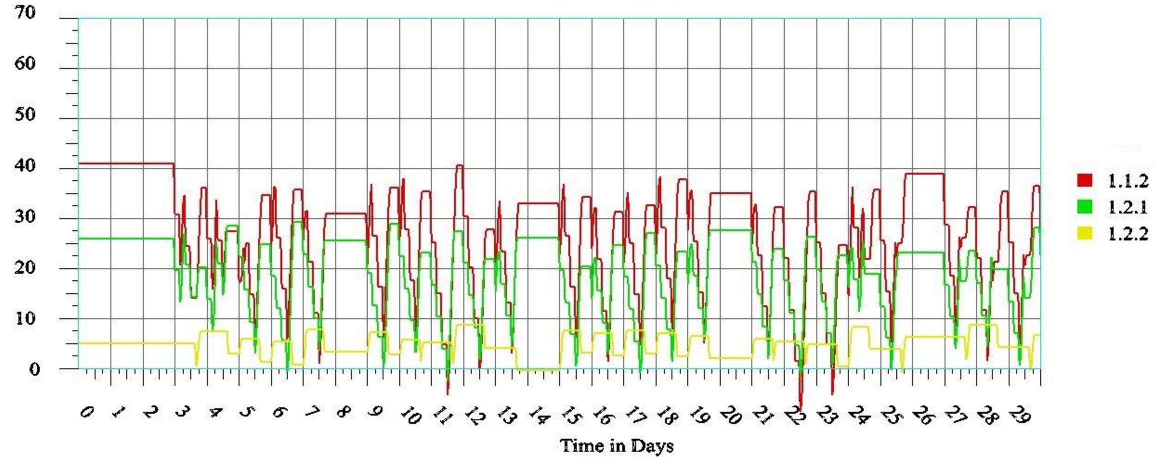
Function		Total area	Free ceiling heigh	Max. ceiling load	Floor load	Min. pillar distance	Water and drain	Steam	Compressed air	Base and cavity	Risk of fire and expl	Special ventilation	Special electricty	
No.	Name	[m²]	[m]	[ton]	[ton/m²]	[m]	A, E, I, O or --							Remarks
1	Foamed 1 conveyor unload (milling)		--	--	--	--	--	--	--	--	--	--	--	
2	Milling machine 1		--	--	--	--	--	--	--	--	--	--	--	Containers near to the forklift roads and availability for tool change
3	Milling machine 2		--	--	--	--	--	--	--	--	--	--	--	Containers near to the forklift roads and availability for tool change
4	Foamed 1 conveyor unload (waterjet)		--	--	--	--	--	--	--	--	--	--	--	
5	Waterjet machine 1		--	--	--	--	--	--	--	--	--	--	--	Containers near to the forklift roads and availability for tool change
6	Waterjet machine 2		--	--	--	--	--	--	--	--	--	--	--	Containers near to the forklift roads and availability for tool change
7	Waterjet cleaning		--	--	--	--	--	--	--	--	--	--	--	
8	Foamed 2 conveyor load (milling)		--	--	--	--	--	--	--	--	--	--	--	
9	Foamed 2 conveyor load (Waterjet)		--	--	--	--	--	--	--	--	--	--	--	
10	Foamed 2 conveyor unload		--	--	--	--	--	--	--	--	--	--	--	
11	Laser		--	--	--	--	--	--	--	--	--	--	--	Tool change must be possible
12	U.S. welding 1		--	--	--	--	--	--	--	--	--	--	--	
13	U.S. welding 2		--	--	--	--	--	--	--	--	--	--	--	
14	I.R. welding		--	--	--	--	--	--	--	--	--	--	--	Tool change must be possible
15	Quality control		--	--	--	--	--	--	--	--	--	--	--	
16	Cockpit buffer load		--	--	--	--	--	--	--	--	--	--	--	

Appendix B

Buffer levels at finished IP buffer



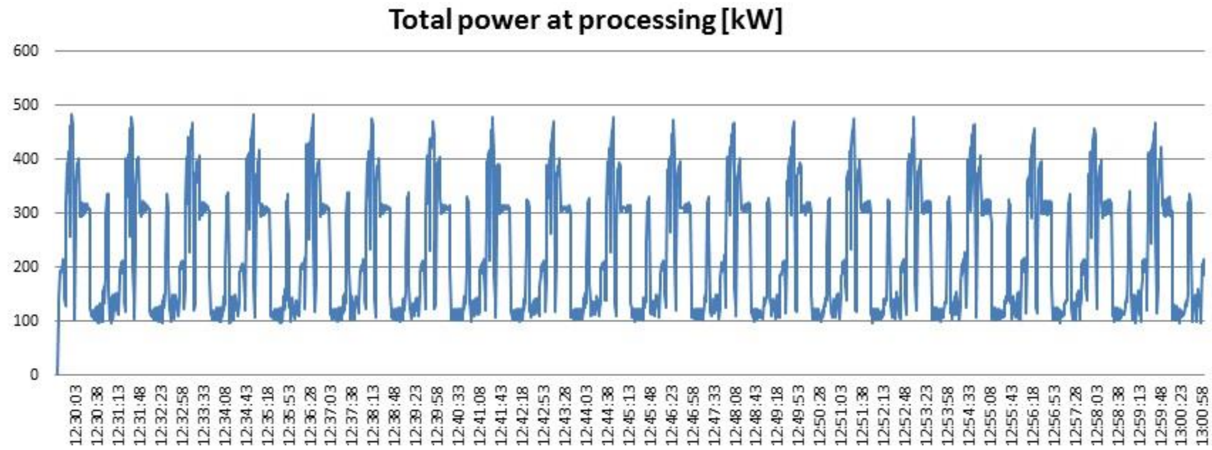


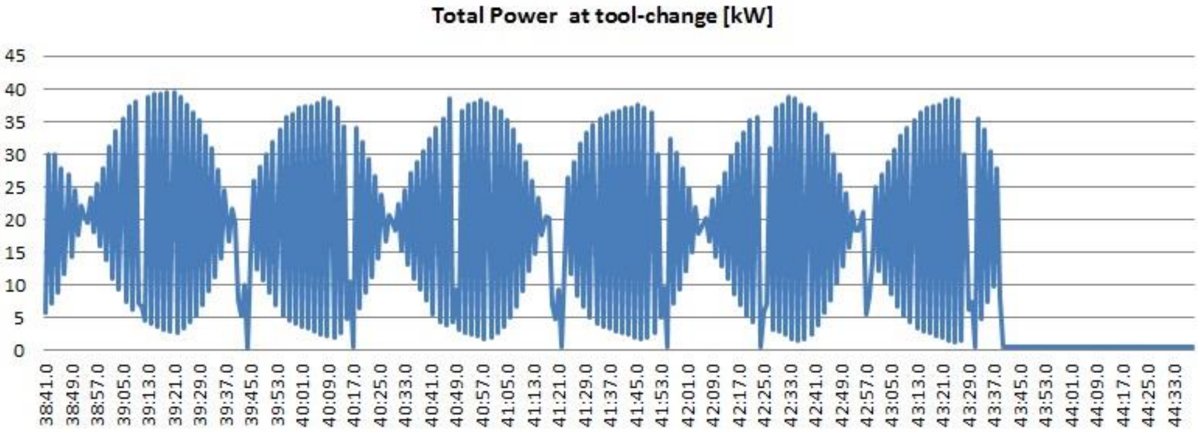


Appendix C

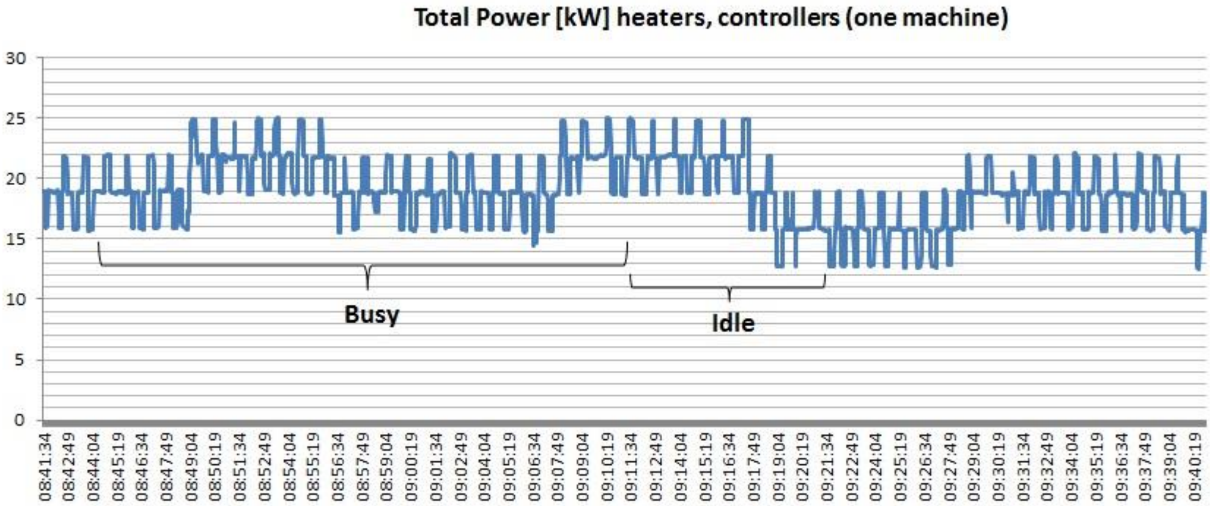
Machine power measurements

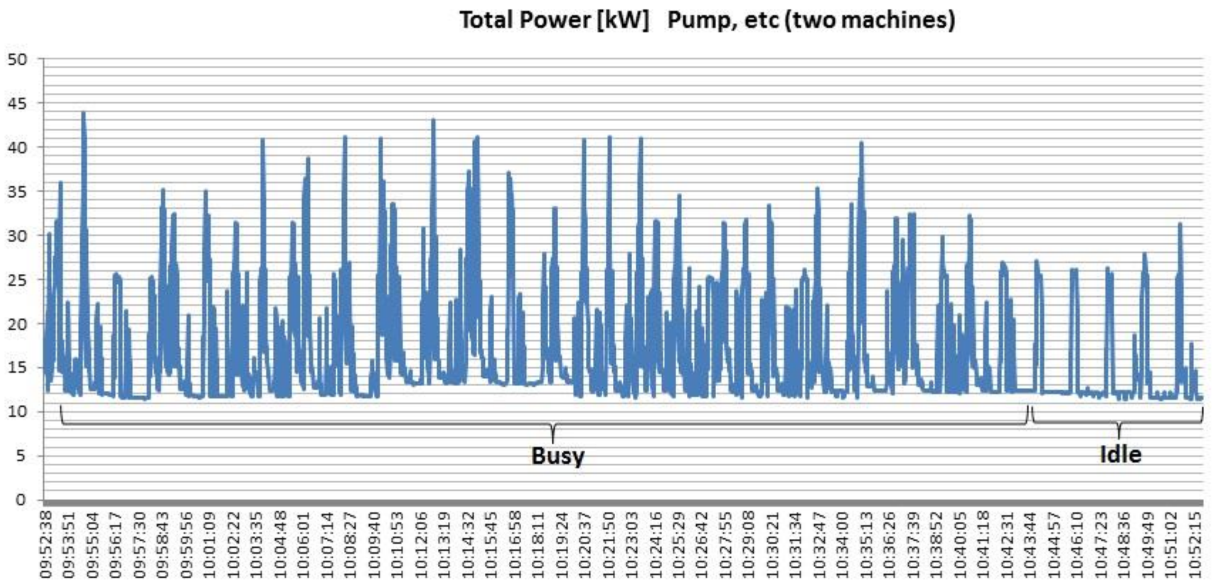
Injection molding

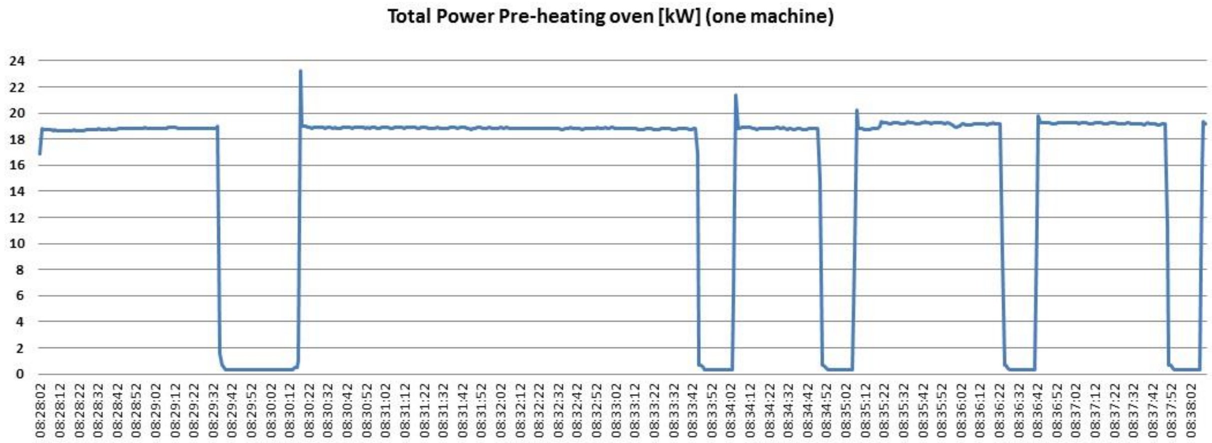




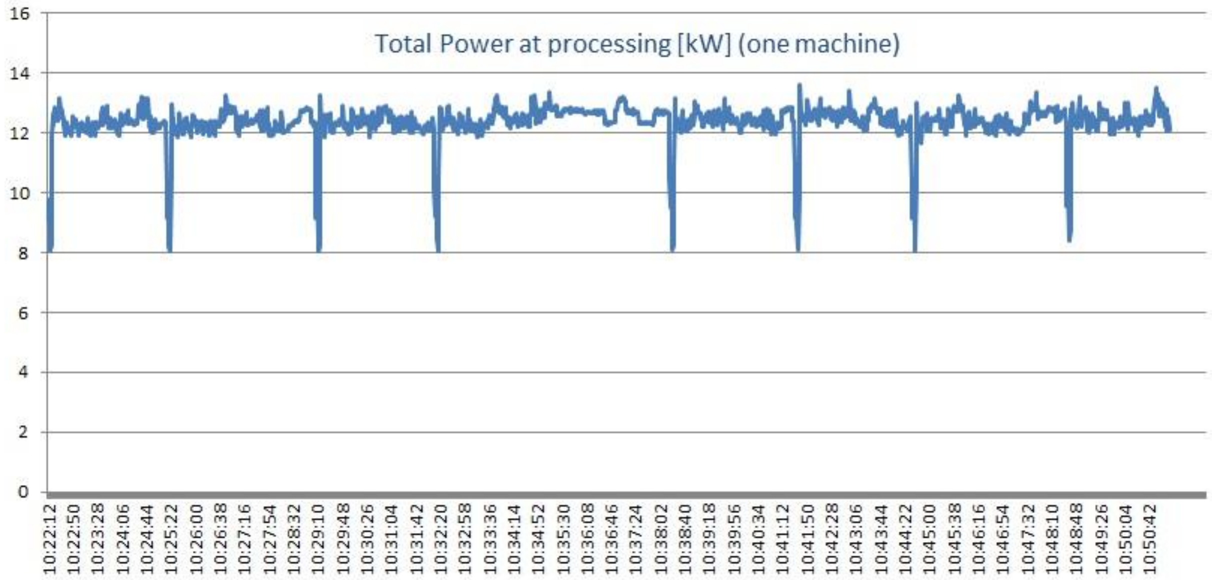
Foaming

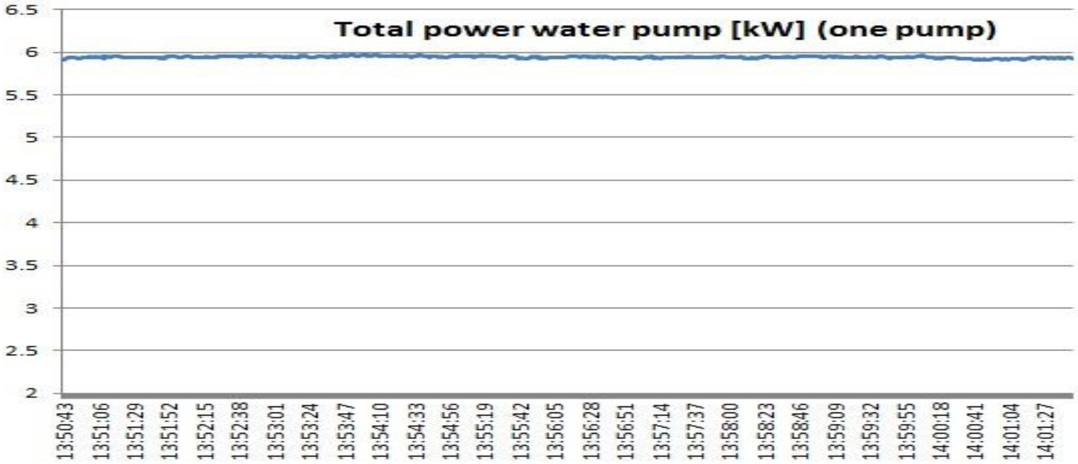



Total Power [kW]   Pump, etc (two machines)
0
5
10
15
20
25
30
35
40
45
50
Busy
Idle
09:52:38
09:53:51
09:55:04
09:56:17
09:57:30
09:58:43
09:59:56
10:01:09
10:02:22
10:03:35
10:04:48
10:06:01
10:07:14
10:08:27
10:09:40
10:10:53
10:12:06
10:13:19
10:14:32
10:15:45
10:16:58
10:18:11
10:19:24
10:20:37
10:21:50
10:23:03
10:24:16
10:25:29
10:26:42
10:27:55
10:29:08
10:30:21
10:31:34
10:32:47
10:34:00
10:35:13
10:36:26
10:37:39
10:38:52
10:40:05
10:41:18
10:42:31
10:43:44
10:44:57
10:46:10
10:47:23
10:48:36
10:49:49
10:51:02
10:52:15


Total Power Pre-heating oven [kW] (one machine)
0
2
4
6
8
10
12
14
16
18
20
22
24
08:28:02
08:28:12
08:28:22
08:28:32
08:28:42
08:28:52
08:29:02
08:29:12
08:29:22
08:29:32
08:29:42
08:29:52
08:30:02
08:30:12
08:30:22
08:30:32
08:30:42
08:30:52
08:31:02
08:31:12
08:31:22
08:31:32
08:31:42
08:31:52
08:32:02
08:32:12
08:32:22
08:32:32
08:32:42
08:32:52
08:33:02
08:33:12
08:33:22
08:33:32
08:33:42
08:33:52
08:34:02
08:34:12
08:34:22
08:34:32
08:34:42
08:34:52
08:35:02
08:35:12
08:35:22
08:35:32
08:35:42
08:35:52
08:36:02
08:36:12
08:36:22
08:36:32
08:36:42
08:36:52
08:37:02
08:37:12
08:37:22
08:37:32
08:37:42
08:37:52
08:38:02

Water jet


Total Power at processing [kW] (one machine)
0
2
4
6
8
10
12
14
16
10:22:12
10:22:50
10:23:28
10:24:06
10:24:44
10:25:22
10:26:00
10:26:38
10:27:16
10:27:54
10:28:32
10:29:10
10:29:48
10:30:26
10:31:04
10:31:42
10:32:20
10:32:58
10:33:36
10:34:14
10:34:52
10:35:30
10:36:08
10:36:46
10:37:24
10:38:02
10:38:40
10:39:18
10:39:56
10:40:34
10:41:12
10:41:50
10:42:28
10:43:06
10:43:44
10:44:22
10:45:00
10:45:38
10:46:16
10:46:54
10:47:32
10:48:10
10:48:48
10:49:26
10:50:04
10:50:42


Total power water pump [kW] (one pump)
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
13:50:43
13:51:06
13:51:29
13:51:52
13:52:15
13:52:38
13:53:01
13:53:24
13:53:47
13:54:10
13:54:33
13:54:56
13:55:19
13:55:42
13:56:05
13:56:28
13:56:51
13:57:14
13:57:37
13:58:00
13:58:23
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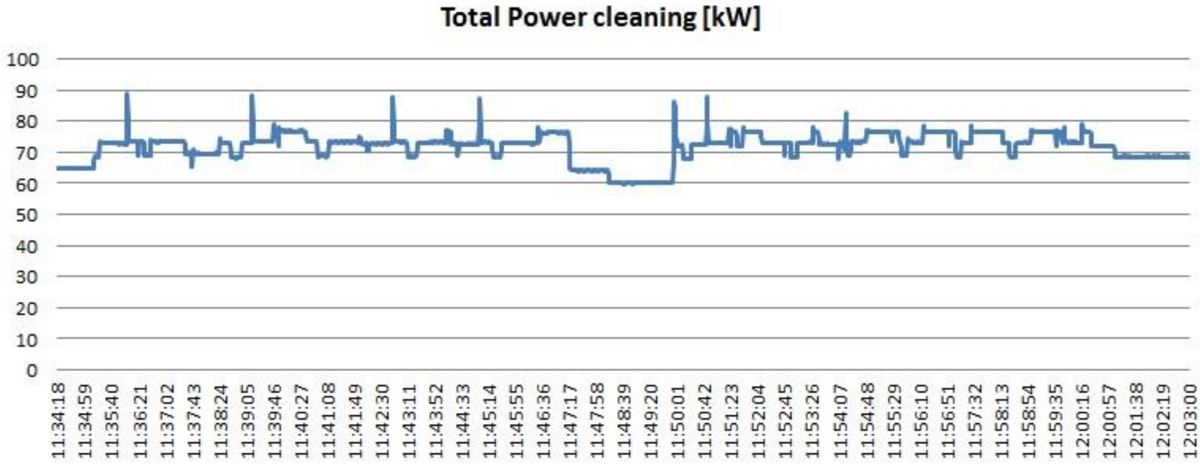
14:00:18
14:00:41
14:01:04
14:01:27


Total Power cleaning [kW]
100
90
80
70
60
50
40
30
20
10
0
11:34:18
11:34:59
11:35:40
11:36:21
11:37:02
11:37:43
11:38:24
11:39:05
11:39:46
11:40:27
11:41:08
11:41:49
11:42:30
11:43:11
11:43:52
11:44:33
11:45:14
11:45:55
11:46:36
11:47:17
11:47:58
11:48:39
11:49:20
11:50:01
11:50:42
11:51:23
11:52:04
11:52:45
11:53:26
11:54:07
11:54:48
11:55:29
11:56:10
11:56:51
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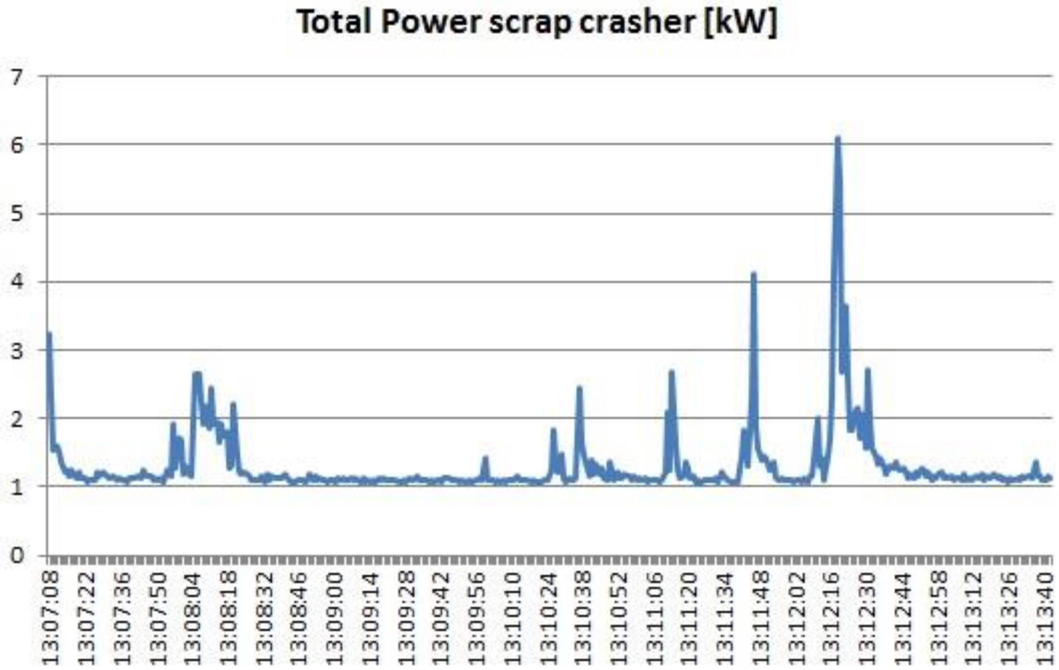
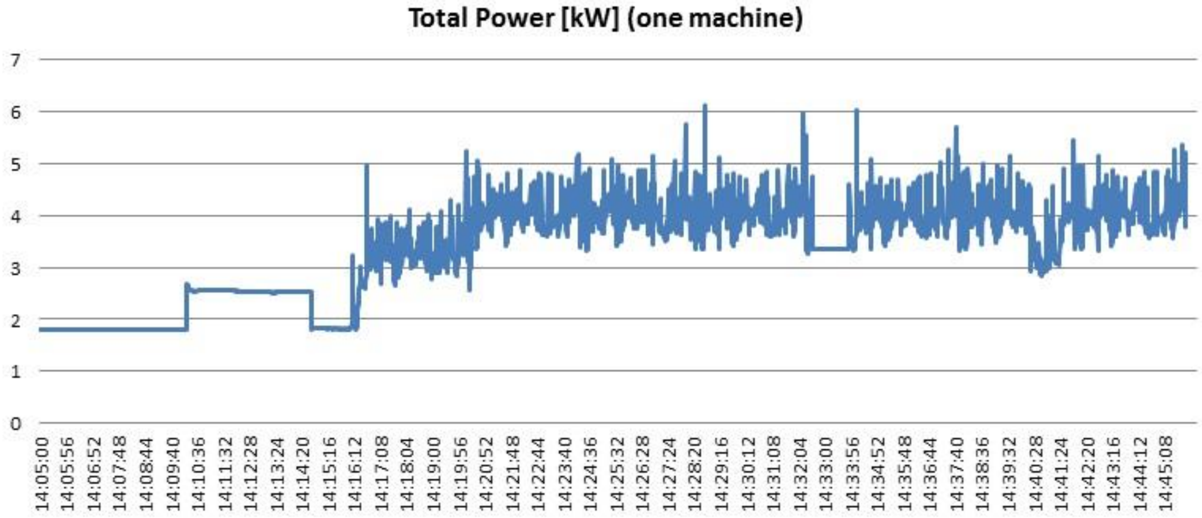
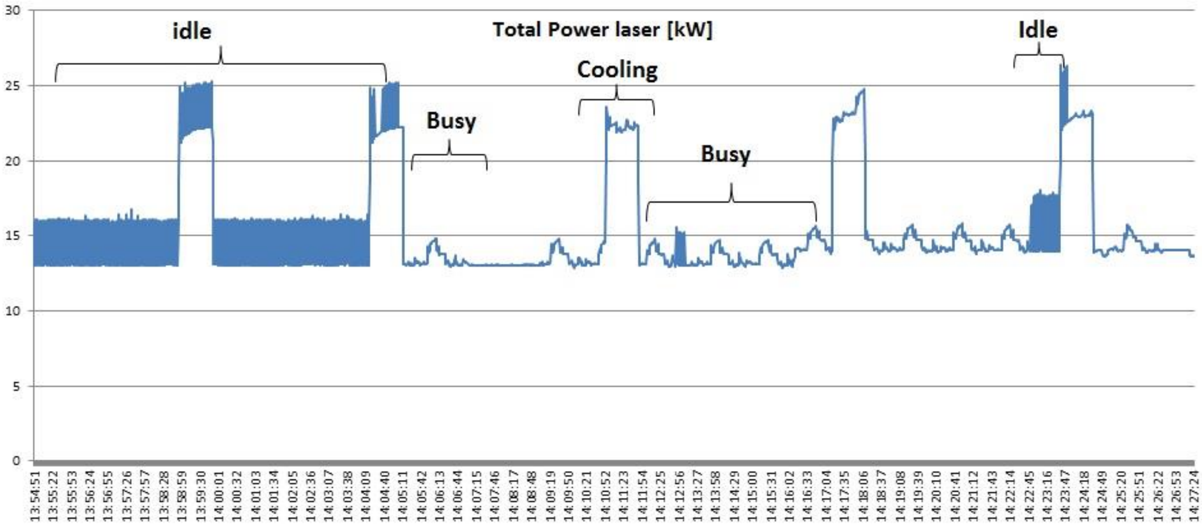
12:02:19
12:03:00


Total Power scrap crasher [kW]
7
6
5
4
3
2
1
0
13:07:08
13:07:22
13:07:36
13:07:50
13:08:04
13:08:18
13:08:32
13:08:46
13:09:00
13:09:14
13:09:28
13:09:42
13:09:56
13:10:10
13:10:24
13:10:38
13:10:52
13:11:06
13:11:20
13:11:34
13:11:48
13:12:02
13:12:16
13:12:30
13:12:44
13:12:58
13:13:12
13:13:26
13:13:40

Milling



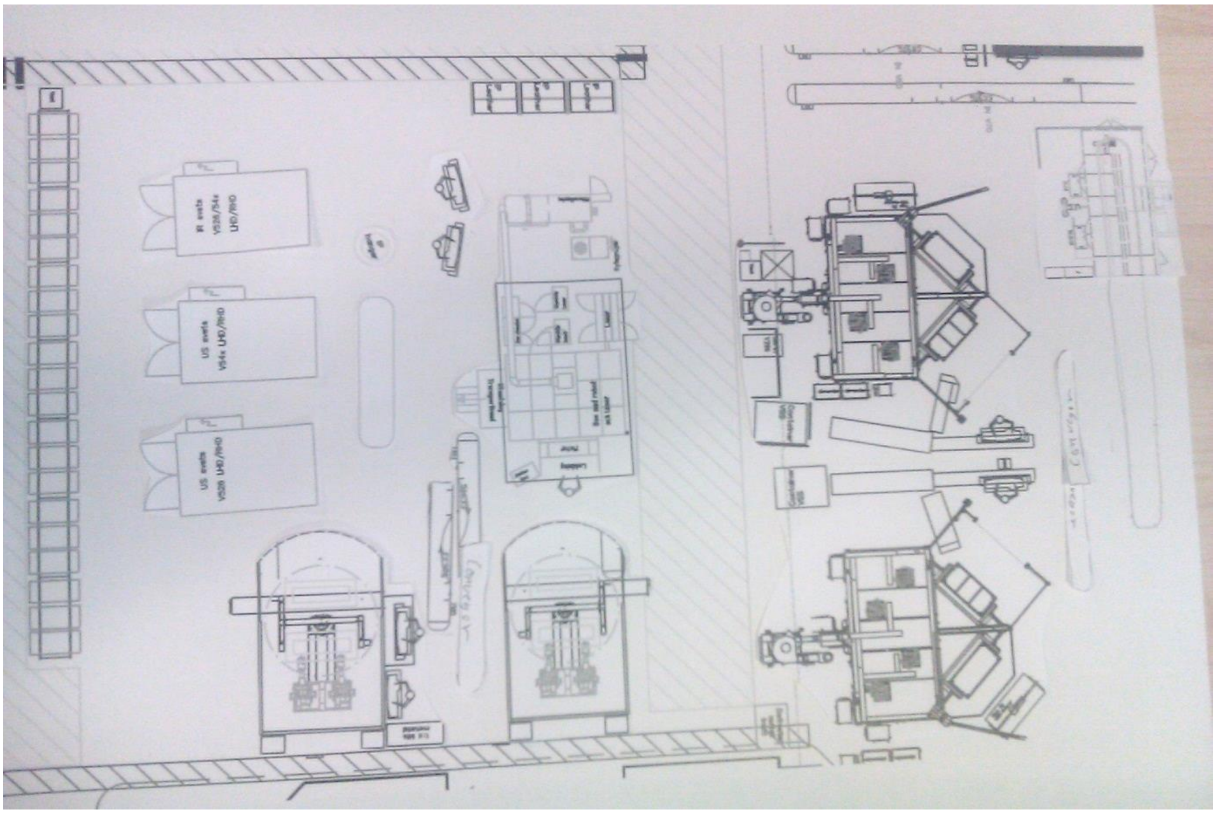
Laser



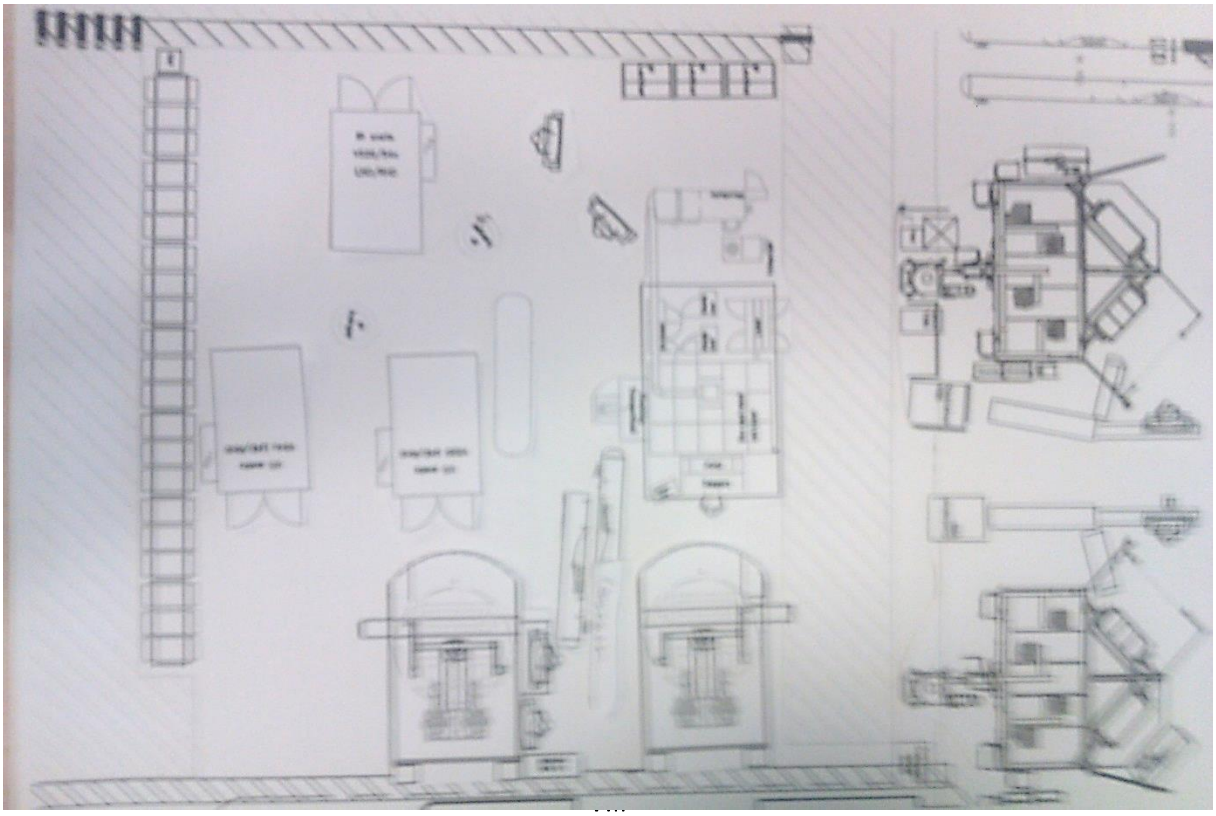
Appendix D

Conceptual layout proposals

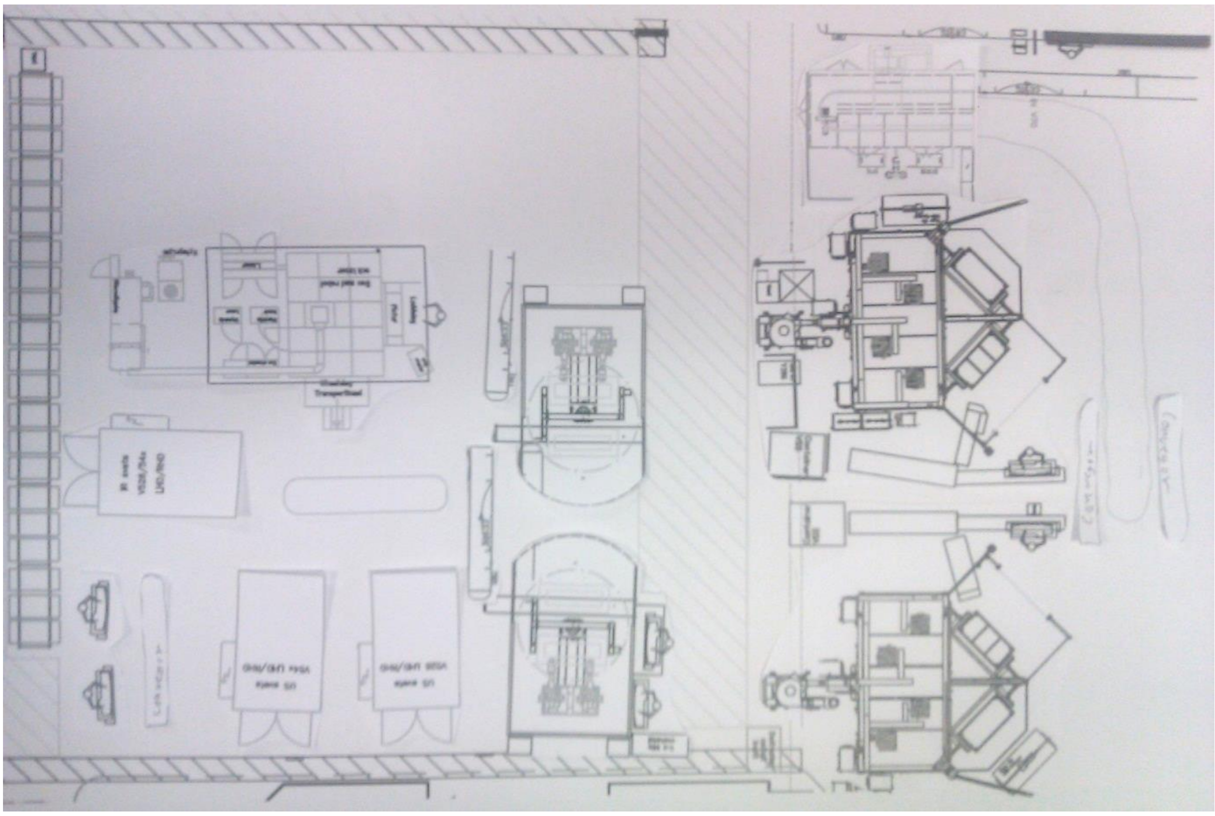
Layout 1



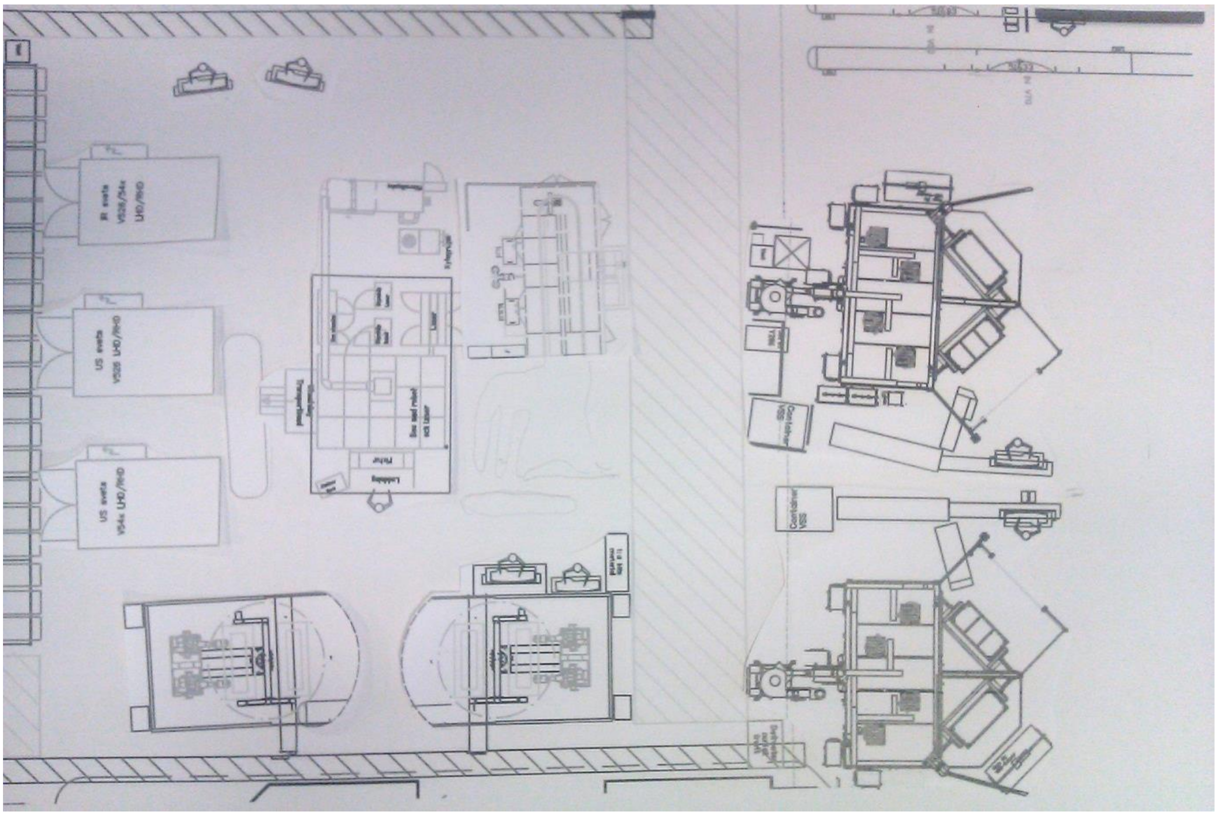
Layout 2



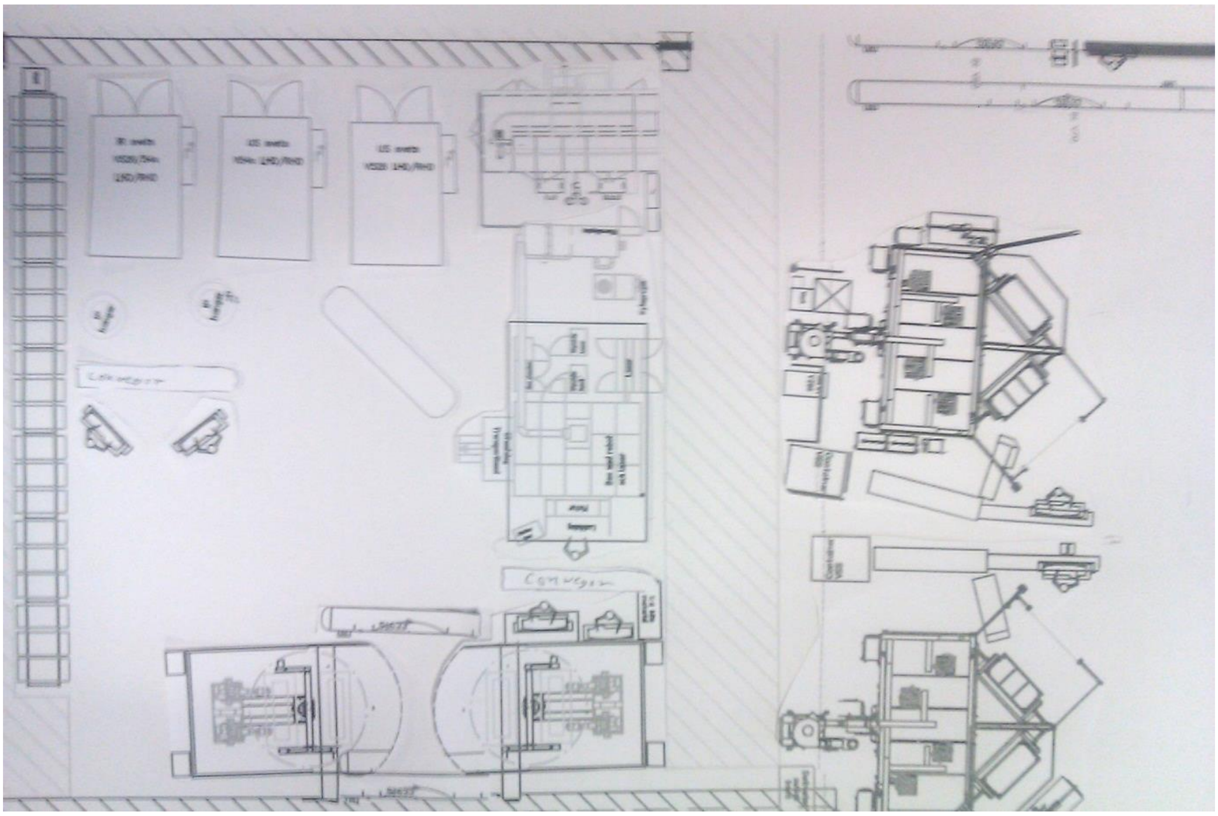
Layout 3



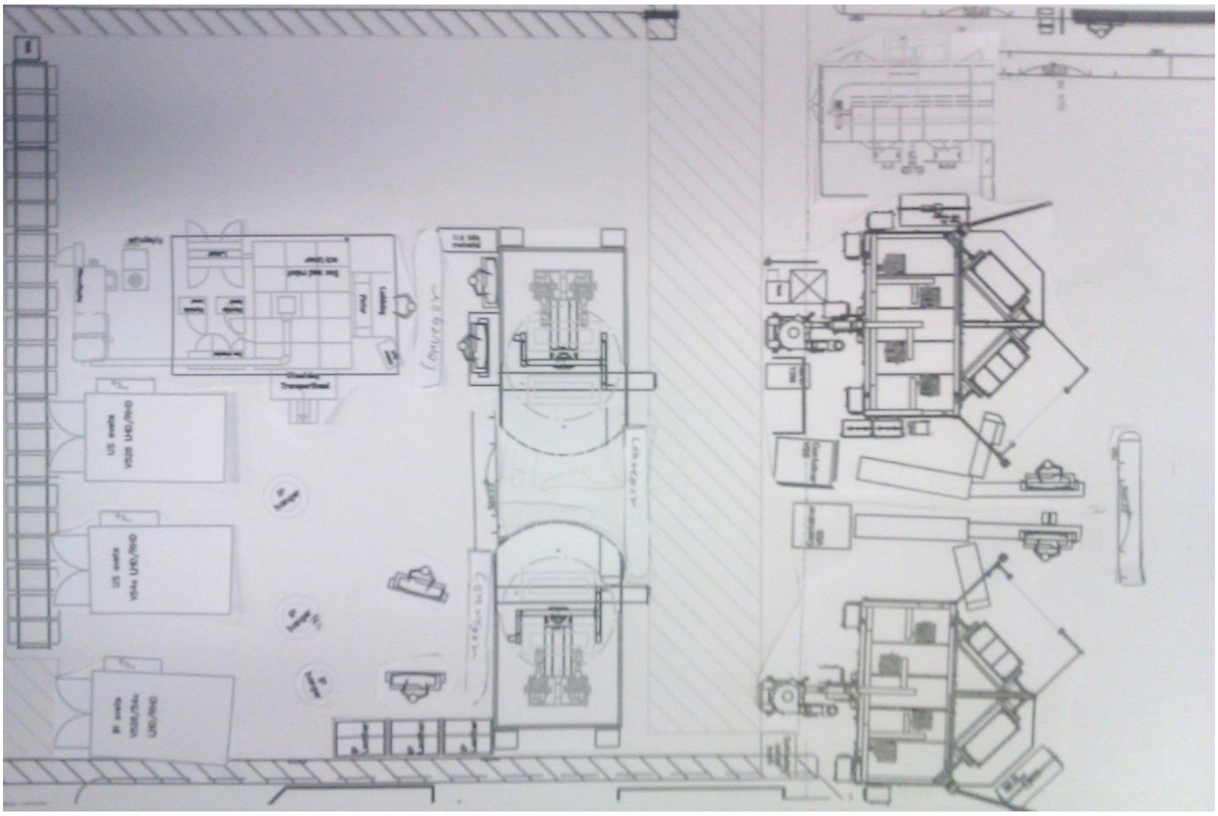
Layout 4



Layout 5



Layout 6



Layout 7


US svets
V526 LHD/RHD
US svets
V54x LHD/RHD
IR svets
V526/54x
LHD/RHD
Box med robot
och Laser
Laser