INTERNATIONAL
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REDESIGN OF PROCESSES IN INDUSTRY PRODUCING FLEXIBLE POLYURETHANE FOAM

SCHOOL OF ECONOMICS, BUSINESS ADMINISTRATION & LEGAL STUDIES / SCIENCE AND TECHNOLOGY OF

A thesis submitted for the degree of
Master of Science (MSc) in Strategic Product Design

Magoulas Spyridon

ID: 1106170015

Supervisor: Dr Katsaliaki Korina

JANUARY 2020

Thessaloniki-Greece

Abstract

Polyurethane foam is a material that is used in a significant variety of sectors. Industries producing PUF are still growing their market share and there is margin for innovative solutions related to production operations and new final products. The current study aims to map the functions of a specific industry by an operations management perspective. The process of mapping the operations of the industry led to the investigation of problems related to the use of working space, waste of raw material, waste of motion etc. The main scope was to suggest realistic and cost effective solutions as well as an improved layout design in order to reduce the existing barriers and increase efficiency and effectiveness.

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Chapter 1: Introduction

1.1 Modern definition of Operations Management

Every organization's objective is to deliver a service or a product to the customer. The process of transformation, "operations", makes use of the input resources and add value to the output product for the customer. Materials, information and customers are called transformed resources, similarly facilities and staff comprising the transforming resources (as it is illustrated in Figure 1). According to Greasley (2009) operations process is a way of transforming a set of input resources into outputs of products and services. Operations Management is the function used by business aiming for coordination, planning, and controlling of processes and resources. By using specific strategy related to OM organizations can take advantage of being efficient and effective. The main strategic drivers are costs, sequence of operations, logistics, quality systems, productivity and allocations of resources. After all, selecting the appropriate strategy will lead to profit maximisation, customisations, quality, flexibility, quick response, creativity and innovation, reliable delivery and better after sale service (Ahmed et al., 1996 cited in Yu & Ramanathan, 2012).

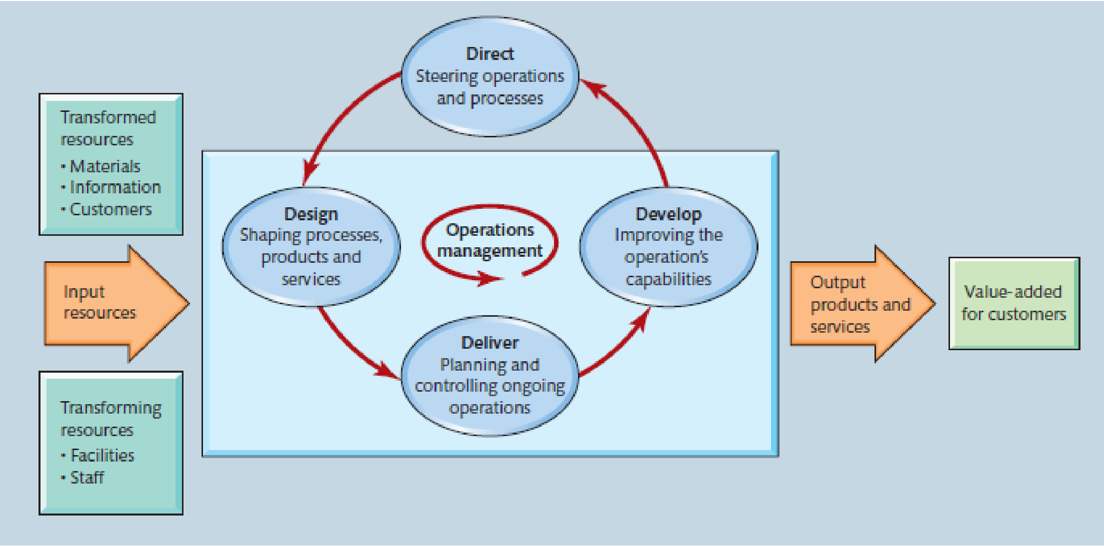

Figure 1: Graphic representation of OM' transformation role

(Source: Nigel Slack et al, 2013)

1.2 History of Operations Management

According to Skinner (1985), for the first time the functions of Operations Management introduced the period of 1890-1920 with the contribution of Frederick W. Taylor, Frank and Lillian Gilbreth and Henry L. Gantt. Later this era was established as ¨scientific management¨. It is based on observation, measurement, analyzing and improvement of work methods and economic motivation. The main scope was to find the best way to accomplish each job. In contrast to the great economic crisis of 1929 the period between 1920 and 1960 is described as the golden age for the development of industry in the USA (Hopp and Spearman, 2001). Specifically, they were focused on labor productivity improvements (time and sequence of tasks), layout, production control and queuing theory. The contribution of Taiichi Ohno were significant for Toyota Motor company as a new manufacturing system was developed focusing ¨just in time¨ and automation. After World War II algorithms and methodologies were developed to solve problems related to optimization (Chopra et al., 2004). Although studies have been done on aggregate capacity planning, inventory planning and quality control still were not used widely. In 1960s, Orlicky and O. Wright started using computers to give solutions in production control issues. In the following decade MRP systems were developed followed by information systems and databases as there was necessity for handling of data. During 1980s, operations management has been accepted globally as a functional discipline of organizations. Due to the evolution of computers and the need for better planning and control MRP II was developed by Gene Thomas at IBM. Finally, as internet was widely established Enterprise Resource Planning software becomes a key tool in order to coordinate, plan and control all the functions of the companies(distribution, allocation of resources, accounting, manufacturing process, procurement, inventory handling, human resources). In Figure 2 the most important innovations of operations management are illustrated.

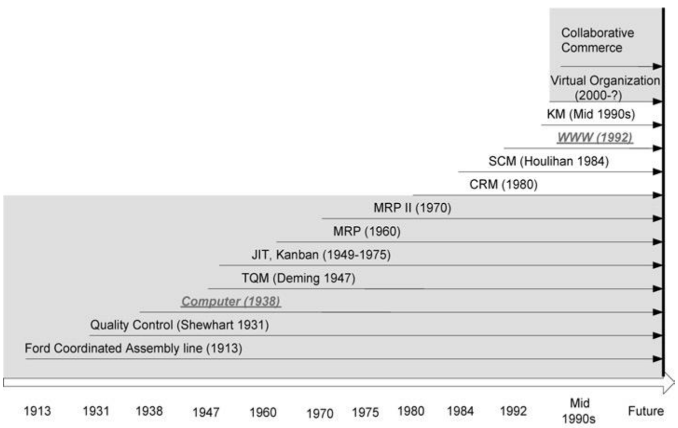

Figure 2: Innovations in Operations Management

(Source: Adapted from Nankervis et al, 2015)

1.3 The necessity for manufacturing companies to adapt Operations Management tools.

The globalization obligates not only multinational companies but also the small and medium enterprises to improve both the inner and outer environment so that they will be competitive and sustainable. SMEs are businesses that employs a small number of employees maintaining revenues and assets. As long as the role of SMEs in each country is important for their economy, the government supports them to help keep them viable and competitive. Managing internal processes for SMEs is often based on learning by doing. By solving practical issues in order to adapt to the market they develop skills that transform to internal knowledge. It is a significant fact that in SMEs there are developed strong relationships between members of the companies and suppliers or other personnel of professional organizations. By knowing it they can benefit from this knowledge and start using new analytical and business tools for better planning of production and improve the manufacturing processes in order to optimize and integrate the supply chain.

Operations management tools are necessary for SMEs as they are vital for control and improve quality of products. Another reason to adapt OM practices is to improve the overall efficiency. By knowing production cycles and times companies can be reliable to their customers concerning delivery times, an indicator for quality of service. Moreover, improvement of production processes creates benefits as waste reduction of raw materials and intermediate product. It is significant to handle stock and reduce it to a safety level as space for inventory creates in SMEs is limited. The volume of work in progress needs to be controlled for the same reason.

In conclusion, it is a matter of survival for SMEs to have a clear view of the function of their business so that they can be innovative and keep their market share and grow. By adopting new technology tools they can deplete production processes and human resources used. All of the above have an impact on the economic environment of the company. More significantly, reducing ordering cost of raw materials, cost of delivery, cost related to defective products, cost of inventory, cost of wastage in production and energy cost conserves economic resources. It is important to mention that SMEs are struggling to find cash flow and they are often not get paid in time. So investing in innovation is a difficult process and saving cost from each process is crucial.

1.4 Motivation

After 10 years of financial crisis in Greece the number of companies that disappeared is 244,712. A great number of them closed because of bankruptcy, other closed due to competitiveness and not being viable. High taxation of Greece combined with lower salaries in Balkan lead domestic companies as well as multinational companies to depart from Greece and establish their headquarters and operations in the neighboring countries where financial and political conditions were more stable. In the region of Thrace specifically in Xanthi more than 30 industries closed for the reasons mentioned above. As a result unemployment increased and overall productivity is decreased. There some big business that closed such as the Cooperative Meat Production and Trading Company (ΣΕΠΕΚ), the Paper Manufacturing Company of Thrace (DIANA), Pyramis, Co-operative Company of Industrial Development of Thrace (ΣΕΒΑΘ), Aluminum Industry of North Greece and Greek sugar industry.

It is a fact that bankruptcy of industries and enterprises affected the suppliers and other stakeholders of the supply chain pushing them to the same direction. Cooperating companies left without being paid for the products sold to the bankrupted companies. This situation increased their debt, created cash flow problems and lost the ability to get loan from banks. The industries that survived fired employees as a consequence of decrease in demand and a way to reduce costs. Furthermore, financial liquidity prevents companies from investing in new machinery, expanding business and adopting new technology. These are tools of great importance for companies to compete in the global market.

It is a challenge for small and medium enterprises to find ways to improve their overall performance taking into consideration that circumstances are not conducive. Furthermore, overcome internal constraints, increase market share and focus on customers are important key drivers connected with Operations Management techniques.

Understanding the Lean Manufacturing philosophy would offer great advantages to Greek companies. It is interesting to mention that 39% of respondents in Greece associate lean manufacturing with workforce reduction (Konstantinos Salonitis and Christos Tsinopoulos). Also, the level of understanding lean manufacturing implementation affiliates more with the durations implemented and not with the size of the company. Finally, it is crucial to investigate if it possible to overcome key barriers of investment costs, management barriers related to poor knowledge or poor belief on the approach. Also, workforce related barriers such as fear of change, employees' fear of job cutting and lack of knowledge and understanding.

1.5 Objectives of Dissertation

The objectives of this study are to make the profile of the specific industry producing flexible polyurethane foam and understand the way that most SMEs operate in Greece. It is important to analyze the current situation and compare it with management techniques used by other companies. Their operation activities are focusing in producing PU foam blocks and layers in a variety of more than 15 different qualities. The company's products are applied in the sector of furniture construction, hospital sector, packaging services, hotels and other industries. It is expected to note down and answer the following questions.

1. Is it possible to manage in a better way raw materials?
2. Do an improved layout design of the industry can give benefits?
3. How to reduce wasted materials and defective products?
4. Is it possible to reduce stock without affecting customer lead time?
5. Does demand forecasting assist in better organizing of production?
6. Considering the current conditions after collecting and analyzing data, what kind of applicable recommendations could be made?

Chapter 2: Literature Review

2.1 The main reasons for redesigning

In the Greek manufacturing sector the industries that started operating after the decade of 1980 had lack of knowledge about management and optimization. Due to this fact they developed structural business models based on experience. Furthermore, the new trends in did not transferred and applied in business because of the absence of managers in small business. In order to be competitive, companies must achieve excellence in managing their

Manufacturing operations. The redesigning-reengineering process focuses on the operations performed and how they should be designed to be functional, ergonomic and qualified. It embodies mapping and analyzing processes so that performance being improved and implement new solutions.

It is important for business to be sure that all operations are oriented towards the goals and they function without incidents. By redesigning processes superfluous processes that slowed down the overall productions are removed. Employees will find it easier to follow a shorter path and be satisfied. Also there is more time for employees to perform meaningful work. So overall efficiency and satisfaction is increased. The reengineering process aims to improve the overall business functions, focus on the firm's goal and create an energetic and innovative business environment. As a result, the enterprise will have lower operation costs, better organizational structure, clear objectives, more time for new product development and increased profit. Last but not least, satisfaction of employees is a possible outcome that leads to creativity.

2.2 Layout and flow

Product and service choices, capacity planning, process selection, and layout of facilities are among the most basic decisions managers make because they have long-term consequences for business organizations, and they impact a wide range of activities and capabilities (Stevenson William J.) .As it was mentioned above, small business tend to be managed by the owner. The involvement of the owner manager is a basic factor that distinguishes small from big companies considering the way they are managed. Small businesses are more personalised and rely on the skills and experience of the owner. Furthermore, there is less time and skills for improvements on the design of business and operations.

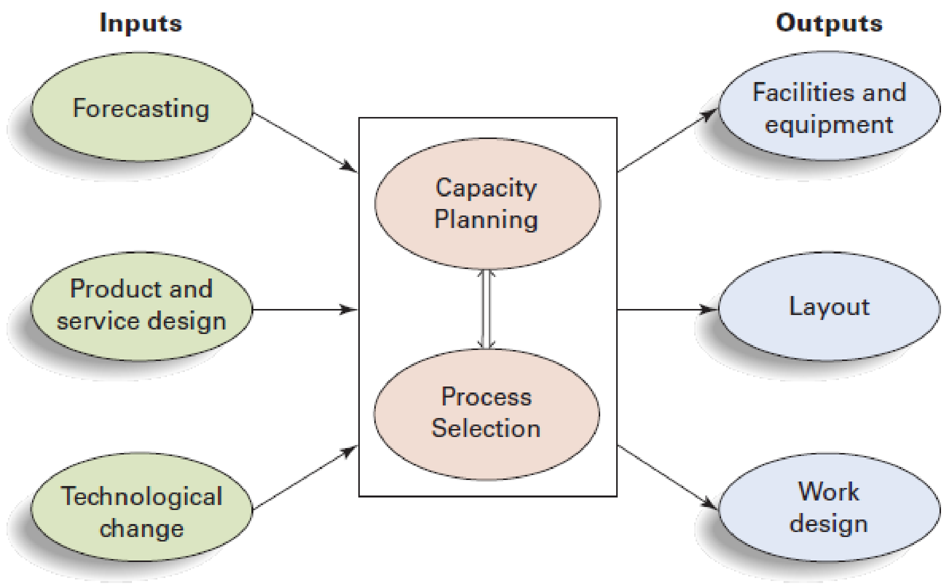

Figure 3: Process selection and capacity planning influence system design
Source (Stevenson William J., 2012)

In figure 3 it is illustrated the dependency of capacity planning and the selected process. It is obvious that when it is planned to manufacture a new product, make technological changes to adopt to the competitiveness of the market and forecasting influencing capacity planning and process selection. Furthermore, capacity planning and process selection are correlated. Both of them significantly affect facilities equipment, the layout of the industry and the designing of work. Finally, adapting an efficient layout design and flow which leads to optimization of space, facilitating moving in the industry, eliminate unnecessary movements of workers or materials, extension in the layout, the increase capacity production and provide safety for workers and production plant.

2.2.1 Production processes

Concerning product variety and production volume production processes are divided in five categories. Figure 4 presents the correlation between facility layout and production processes. Definitions of categories are summarized as follows.

A project is a unique non-repetitive set of activities directed toward a unique goal within a limited time frame (Stevenson William J, 2012). It is a complex process of high customization with high variable costs and cost per unit. The scheduling and the control of a project is crucial.

Job shop is a low scale manufacturing process of high variety of products. Each job requires highly skilled workers and unique operations. It is flexible and products are made to order.

Batch process implies for medium quantities of products that are variable. It is not a repetitive process. Furthermore, it is flexible for new products as machines are not connected with conveyor. Workforce does not need to be highly skilled. Products of this process are made to stock and are oriented toward mass market.

Mass production is a repetitive automated process (production line, assembly line) for producing standardised products in high volumes. The variety of products per line is low as the adjustment of equipment is specific. There is no need for special skilled workforce except from monitoring the equipment. As it the most efficient process, changing the sequence of the production line is a difficult task.

Flow or continuous production is appropriate for very low varieties even only one kind of product. Products are highly standardized in huge volumes and the he cycle time is very low. Similarly to the mass production changes cost in time and money. Finally, machine defects affect the whole process.

In the specific PU foam industry batch processes are implied as the orders of customers are medium in quantity and they are variable for each customer.

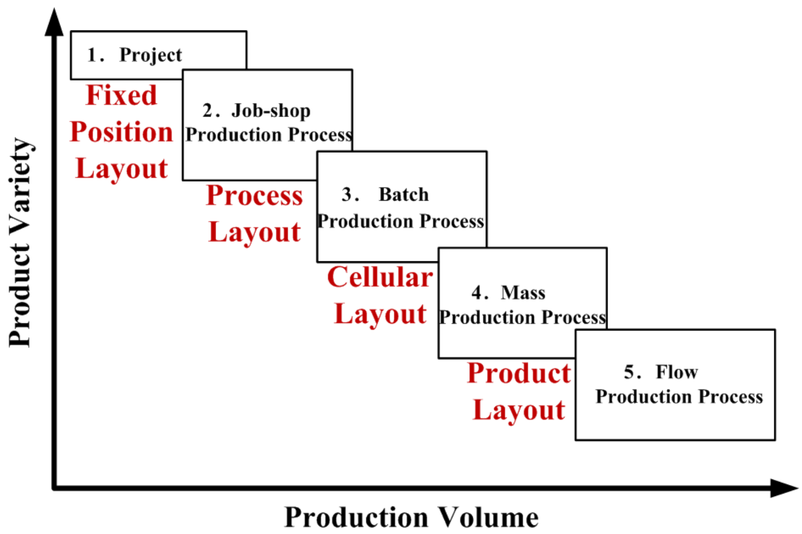

Figure 4: Types of production processes and facility layout relationship

Source (György Kovács and Sebastian Kot, 2017)

2.2.2 Main types of facility layout

Fixed Position Layout is appropriate for products that are large and bulky and its movement is impossible. Workers, raw material and machine equipment are moved to the production station. Delivery of raw materials and completion time are the most important factors. There are disadvantages related to space such as crowded work areas and little lack of storage space. Problems related to space may affect material handling.

Process or functional layout is based on the nature of process through which the product moves to be manufactured. Processes are grouped in departments in which similar kind of activities take place (milling, grinding, drilling, painting, assembling, packaging). Items that moved through departments in lots and batches. This layout is easier to supervised and more flexible. The success of one operation does not affect directly another operation as items moved in batches. Also maintenance cost is lower and the disconnection of one machine does not interrupt the whole manufacturing process. Financially, investments for spare parts, extension machines or software updates are lower than in product layouts. In contrast to the benefits there are important drawbacks to mention. Due to the discontinuous nature of layout work in progress is increased. Intermediate products increase in-process and reduce the availability of working floor area. Also, through put time is long. Accounting, inventory control, scheduling of efficient batch production become complex activities and need special attention. The lack of well-organized production control creates delays or inefficient use of manufacturing time.

Cellular layout contains machines which are grouped according to the similar process needed for the manufacturing of a family of products that are alike. Before grouping the essential machines it is necessary to identify families of products and train the employees. There are many advantages in this layout like reduction in set up time, in work in progress inventory, in material handling and transportation time. Also they are flexible, less floor space required as there is not work in progress inventory and efficient use of machines and equipment. Additionally, as workers participate in a series of sequencing tasks and observing the manufacturing process boredom is reduced and job becomes more interesting. On the other side, sometimes work in cells may not be balanced due to decrease in demand of a specific family of products. In Contrast to this when there is increased demand in another cell workforce should be adjusted and move. The mobility of operators is possible only if they are multi-skilled and trained in each cell. Investment for cells is higher because similar machines are duplicated in order to be used in different cells.

Product or line layout is used for manufacturing standardized products of high volumes. Machines are grouped sequentially in a conveyor line and the product flows on the conveyor. In this layout there is less need for scheduling as there is mechanical pace and automation. It is a beneficial way of production as delay is eliminated. Due to the continuous flow of products work in progress is not accumulated. Also there is less need for control and production control is more effective. Conversely, a huge capital investment is necessary as the same machine is needed to be bought for more than one product lines. The rearrangement of a production line is not an easy process and consumes time as it has been designed for a sequence of specific operations. Also, if a machine stops working it affects the whole product line. Maintaining and fixing the equipment results in higher costs. Finally from the employees perspective working in linear production causes monotony due to the repetitive tasks.

The current layout of the PU foam industry is oriented around processes deploying the advantages mentioned above. Implying characteristics of cellular layout combining them with process layout could result in more efficiency as it will be proposed in Chapter 4.

2.3 Inventory management

Keeping inventory of raw materials, partially completed goods or final products is crucial for the efficient functioning of business. It is important for business to keep stock in order to meet the needs of customers and respond to demand. Ordering of raw materials contains ordering cost, cost of handling and space for storage. The right amount of stock keeps production smooth and protects the business from running out of materials. It is important for enterprises to keep safety stock of raw materials to reduce risk. Suppliers' stock out, weather conditions, workers' strikes, customs control, delivery of wrong material and long distances are factors that increase the risk of delayed deliveries. For small business purchasing cost of raw materials from multinational suppliers is not negotiable as prices are defined by them. Ordering cost is depended on the type of cooperation between the supplier and the buyer. In the chemical supplies it is often included in the price of product and there is a minimum order quantity. Furthermore, holding cost of chemical supplies in the polyurethane foam industry contains cost of electricity consumption as a specific temperature is required before production. There are different ordering policies based on how much to order and when to order. Inventory that is intended to meet expected demand is known as cycle stock, while inventory that is held to reduce the probability of experiencing a stock out (i.e., running out of stock) due to demand and/or lead time variability is known as safety stock (Stevenson William J., 2012).

2.4 Enterprise resource planning

Regardless of a company's size today's business functions become more complex and the need for efficient interaction between departments of a company arises and becomes vital. Enterprise resource planning is a strategic tool and business process management software which synchronizes, integrates, and streamlines data and processes of the organization into one single system to gain a competitive advantage in the global market (Antoniadis I. et al, 2010). The right implementation of an ERP system improves functions of financial control, human resources, customer service, supply chain, operations management. Specifically, an ERP software incorporates modules of ERP production planning, ERP purchasing, ERP inventory control, ERP sales, ERP marketing, ERP financial and ERP human resources to an integrated entity (Ignatio Madanhire, Charles Mbohwab, 2006). According to Antoniadis I. et al investigation in 2014 about ERP system adaption of SMEs in Greece it is measured that in a sample of 37 companies there was an average of 6 year experience in ERP implementation. Decision making process becomes simpler and it is crucial for small business to understand this and adapt effective tools as well as they still struggle to achieve this goal. Additionally, it is important to mention that the traditional manual recording and processing of data is time consuming and complex.

Finally, it is beneficial for SMEs to adopt a customized ERP software and integrate the flow of information, improve productivity, maintain a smooth controlling process, reduce operating costs, be more flexible, locating deviations immediately, increase sales and facilitating decision making process. Based in the above long term planning becomes feasible and can generate company's capabilities. Antoniadis I. et al found that the advantage SMEs is saving time but not operational resources and cost. Optimization of function and cost reduction are processes depending on other factors such as personnel's leadership skills, culture and strategy of the firm. To conclude, records and reporting extracted from ERP software related to volume sales, use of raw material and volume of produced products give important data that can be used for forecasting.

In the company an ERP system is used for counting and organizing raw material use and reordering, records of PU foam production and stock, processing of orders and employees' payroll.

2.5 Forecasting

Forecasting is an important process that provides information about future conditions related to demand. Inventory management contains forecasting of supplies for the expected production of a period. Forecasts also affect capacity planning, budgeting and sales.

They cannot be accurate 100% but it is an important tool for decision making. For longer periods forecasts tend to deviate from real demand. Forecasts should be timely, accurate, reliable, expressed in meaningful units and cost effective. In order to choose an appropriate technique the first step is defining the objective of the forecast. Then the time period of forecasting is chosen considering that accuracy is inversely proportional to time. In the next step appropriate data that affect operations are analyzed. Based on the above a specific technique that fits the requirements is selected. After making a forecast monitoring is necessary to calculate its performance. The accuracy of forecast is measured using forecast error which is the difference between the value that occurs and the value that was predicted for a given time period (Stevenson William J., 2012). There are three alternatives to calculate forecast error, the mean absolute deviation (MAD), the mean squared error (MSE) and the mean absolute percent error (MAPE).

By interviewing with the director it was found that the forecasting method that is applied is based on the Mean Absolute Deviation forecasting method.

2.6 Quality Management

Quality is a performance criterion that concerns almost all organizations. Good quality reduces cost of rectification, waste, complaints and returns and increases customer satisfaction. Quality improvement are applied to the each operations of an enterprise. Customer's view of quality is mapped by the gap created in the comparison of its expectations of the product or service receives to the perceptions of the product/service receives. In order to have a clear view of quality first it is necessitated to define the quality characteristics and decide how to measure each characteristic. Setting quality standards is the step that follows and gives the possibility to control quality to those standards.

Total Quality Management is an effective system for integrating the quality development, quality maintenance and quality improvement efforts of the various groups in an organization so as to enable production and service at the most economical levels which allow for full customer satisfaction. (Nigel Slack et al, 2013). TQM aims to meet expectations of customers, to cover each part of the organization, include every person of the company and develop ways to support quality and improvements. Prevention of defects and errors is the main principle of managing quality. Identifying problems and adjust processes to the right way, redesign and improvement of processes, training and retrain employees are related to prevention costs for retain and improve quality.

2.7 A Lean perspective for SMEs

Lean manufacturing or just in time production was created by Sakichi Toyoda, Kiichiro Toyoda and Taiichi Ohno. It evolved from the precursor Toyota Production System created by Taiichi Ohno and Eiji Toyoda. A great number of authors highlight "lean manufacturing" mostly as a way of waste reduction. The term lean refers to the whole philosophy of how to run operations, as a method of how to plan and control operations and a set of tools that improve performance. By reducing each kind of waste, lean principle aims to maximize the value of product. The production is based on a pull system related to customer demand. There have been developed practices and tools in order to apply the lean philosophy to customer relationship, supplier relationship, human resources, manufacturing planning and control, process and equipment. Related to each business area practices and tools are presented in figure 5.

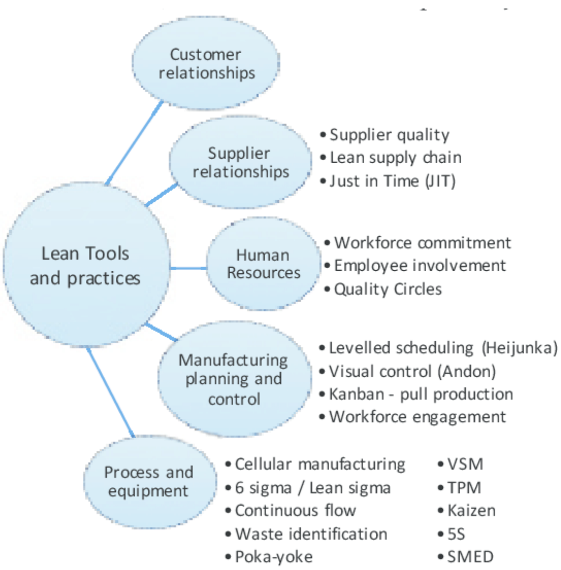

Figure 5: Lean tools and practises

Source (Konstantinos Salonitis, Christos Tsinopoulos, 2016)

Due to the fact that in lean philosophy reduction or elimination of waste constitute a core idea it is important to mention the 7 different types of waste.

1. Over-production waste

Ohno believed that producing more than you need in the near future is the most important kind of waste. Consider that manufacturing is the closest spot to the source that affects the creation of waste in the following processes. With over producing inventory space is covered and floor space is reduced. Additionally it affects cost of storage.

2. Waiting time waste

Equipment efficiency and labour efficiency are two popular measures which are widely used to measure equipment and labour waiting time, respectively. (Nigel Slack et al, 2013). According to Bicheno and Holweg waiting is related to lead time.

3. Transportation waste

Products that flow to the following processes in an inefficient way affect quality and productivity. It happens when the products are handled in the same machine after another. Furthermore, a way to reduce this time layout should change, reduce the distance of machines and the distance of the whole path that the product follows and group machines.

4. Processing waste.

Due to the lack of functional design, lack of knowledge of machine handling or efficient processing some steps may be unnecessary. Training employees to lean thinking can be beneficial. Furthermore, some processes are overloaded with more operators than needed resulting in waste of human resources.

5. Inventory waste

In order to eliminate waste it is needed to find the cause of it (a main cause is overproduction). Inventory is connected with raw material work in progress and final items. Increased inventory captures space and affects moving flexibility as well as lead time.

6. Motion waste

Waste of motion occurs both by human and layout. An operator may makes unnecessary moves that do not add value to the process. Simplifying of work via job redesigning process results in decreasing production time. A poor layout design may involves waste of motion. Unnecessary movement in an industry increases the risk related to both safety issues and declining quality issues.

7. Waste of defects

Defectives may be products that do not approach quality specifications. Errors occur due to wrong processing or due to accidents in transformation when floor space is covered. Furthermore, other quality problems occur during the production phase.

To conclude, it should be mentioned that there is not a specific recipe for success in implementing lean principles. It depends on the manager's perspective to apply techniques that benefit each situation. To conclude, there are important drivers for implementing such as the increase market share, increase of flexibility, the need for survival from internal constraints, focusing on customers, increase the way of working to the best and develop key performance indicators (Konstantinos Salonitis and Christos Tsinopoulos, 2016).

Chapter 3: Case study of specific PUF industry

3.1 Introduction to the company

The company is one of the main manufacturers producing flexible polyurethane foam. Their operation activities are focusing in producing PU foam blocks and layers. The manufacturer delivers intermediate and final products made of polyurethane foam. A big variety of more than 15 different qualities of foam are offered and products delivered as required and specified by the customer. The companies object is to bring customized and qualified and innovative solutions to its customers. The company's products are applied in the sector of furniture construction, hospital sector, packaging services, hotels and other industries. The industry was established in 1973 in Xanthi where there is located the production plants. The industry covers 4700 m^2 at the industrial region of the city. In 1991 a new store department opened in Thessaloniki and in 1995 another one in Athens. The industry owes one horizontal polyurethane foam machine and a series of cutting machines that will be presented thoroughly. In the stores of Thessaloniki and Athens PU foam blocks are transferred to keep stock, processed there and delivered as ordered by customers. The company owes two trucks for delivering products to customers. The company faced some unexpected social related difficulties combined with the socioeconomic issues that aroused due to Greek crisis. After all it survived and start gaining its lost market share and being competitive.

3.2 The methodology

Redesigning processes, operations and layout arrangement of an industrial facility is a complex process that is depended on various factors in order to propose a combined solution that has to be feasible, practicable, flexible and cost effective. The researcher's first move is to have a good background about the product the industry produces. By knowing how it is manufactured, understanding the material properties of polyurethane foam it will be possible to investigate the overall process from base to top in a more integrated perspective and find effective solutions. Notwithstanding that in the beginning there was uncertainty about precise selection of performance indicators eventually it is proved that the first theoretical assumption was within the subject.

In the first period of visiting the industry the main objectives were to observe the way both the employees move in production and office departments as well as the production of polyurethane foam blocks, various of cutting processes and other processes in order to understand the nature of job design and material flow. All these information were written in order to outline and profile the company's structure, functions and strategies.

By organizing these information it was possible to decode and extract the company's philosophy about managing inventory, understand the production strategy, sales strategy, operations management, quality management, forecasting, ERP implementation and the layout of equipment and processes. It is important to mention that due to the lack of professional management personnel all these strategies are not specified by the company as they have established academically. In fact, it would be beneficial for personnel to know the advantages and disadvantages of the strategies using and not just rely on them. By excluding all this information an enterprise will struggle to have a positive environment for making changes.

In the second period of visiting the industry the aim was to repeat observation of employees for evaluating information of the first visiting and increase accuracy. Then a series of unstructured interviews occurred with the operators, the chemical employee, office employees and the chief executive-owner. The interviews aimed at extracting answers about management and organizing issues. The last purpose contained the collection of ERP data about history of sales, annually and monthly production history (total production volume of foam and analytical report of produced foam related to different types of foam), raw material consumption history (focusing on the major) and technical documents about raw material storage capacity and mechanical sketch of the industry.

3.3 Current situation

In order to find the causes that affect quality and overcome obstacles there was a need for categorizing the causes and analyze the roots of the problem. For this reason it was created the fishbone diagram as it is presented in figure 6 to facilitate the detection of factors that influence the overall effectiveness and efficiency of the industry.

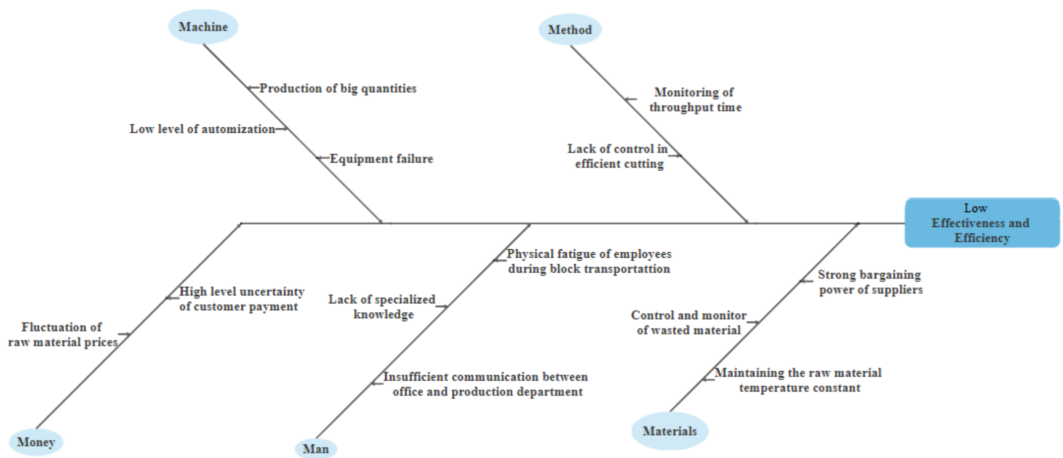

Figure 6: Cause effect fishbone diagram of 5Ms

Source (own)

Based on the most salient factors that were observed in the industry it was made an effort to discover latent causes that affect the total quality, effectiveness and efficiency.

3.3.1 Production Processes

This chapter presents the production processes that occur in order to manufacture flexible polyurethane foam blocks. PU foam Blocks are transformed to delivery products for customers made to order. The sequence of processes is presented as it is indicated in the flowchart of figure 7.

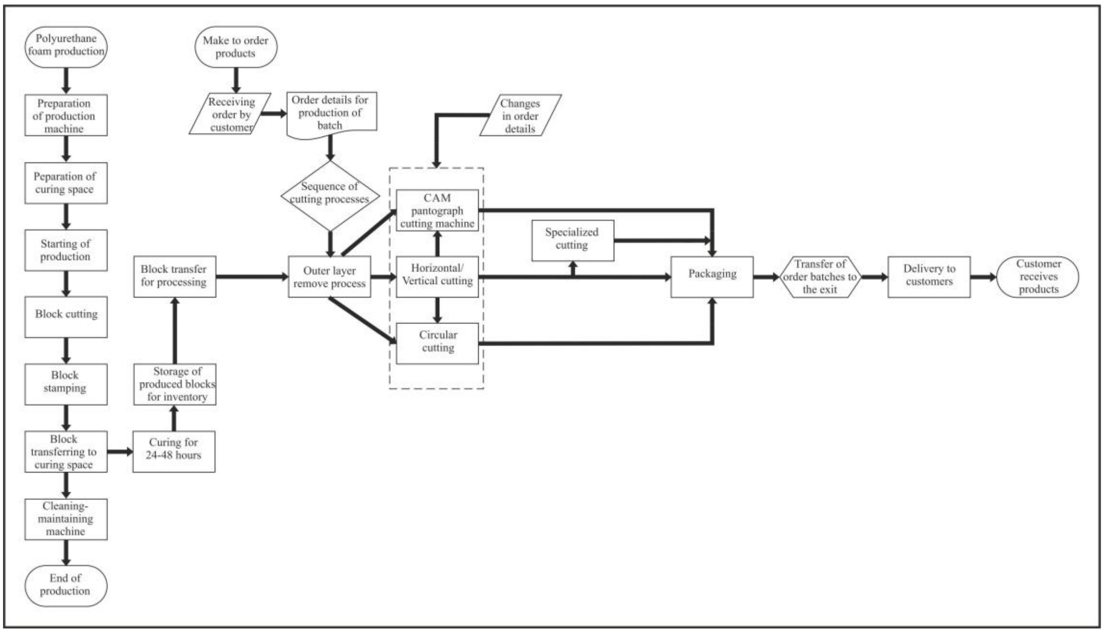

Figure7: Flowchart of processes from start to end

Source (own)

Preparation of production machine

It is the first step before production where the chemical operator checks the machine and adjusts the parameters related to the specific quality of foam that will be produced. Some basic characteristics are the ratio of TDI, selection of polyol for soft or hard foam as well as the ratio of polyols, the pressure of mixing and the velocity of material flow.

Preparation of curing space

Curing time is the amount of time that is necessary for flexible polyurethane foam to acquire its final properties. Curing for polyurethane foam takes from 24-48 hours.

Before this period any sharp pressure on the manufactured block causes irreversible deformation to the block.

Removing equipment or other parts to release space for the new production is necessary.

Beginning of production

The raw material start flow on the line and after a few second the foam starts inflating. At the end of the line there is a vertical knife cutting the outgoing mass in blocks. It is important to notice that due to the release of by-product gases employees have to wear filtered masks. The machine operator controls the process on the machine interface or adjusts different ratios for the manufacturing products.

Vertical Cutting

The continuous produced foam flows on the conveyor. Before reaching the descending conveyor the block is cut in the same length ranging from 200-220cm and then moves forward to be loaded by employees.

Block loading and transferring

At the end of the line workers are waiting to load the block on a trolley. The trolley consists of a squared surface with a horizontal wheeled axis and a leverage for handling. The block is stamped for stock control, then it is loaded on the trolley by the worker and transferred at the curing area. After discharging it, the worker returns to take the next. As the production is continuous workers need to go directly back to the end of the line to load the next part.

End of production

By the end of the production the machine needs to be cleaned. Raw material that are contained in the trial container and pumps of the production machine are removed and collected. It is an essential maintaining process that extends the life cycle of machinery parts. Also the paper that is used to prevent the foam from sticking to the walls of the flowing tunnel is collected and gets discarded.

Inventory

After curing period where the PU foam has been stabilized (24-48 hours) the manufactured blocks are moved for storage with a forklift truck. Blocks are categorized based on their density and quality of foam and banked up.

3.3.2 Cutting Processes

The sequence of operations that are followed after an order has been received depends on the customers specifications about the desired part. Most of the customers ordering semi products. Based on the required part's dimensions the right sequence of operations is decided to cut the block. The first cutting operation aims to remove the external layer of the block and results in better quality and uniformed parts. On average the block's dimension are 2,04m to 2,20m in length, 2,00m to 2,04m in width and 0,92m to 0,94m in height. The bulky blocks are cut in smaller parts to facilitate handling. For manufacturing layers and mattresses the cleaned block is introduced in the round circular cutting machine. Depending on the width of layers the block may needs a vertical cut before added in the circular cutting machine. A number of blocks is loaded on the worktable depending on the surface area of it. Blocks are sliced in the desired thickness. This particular process is characterized by accuracy, automation, high production efficiency, low amount of defective products and low amount of waste foam. It is important to notice that due to the free expansion of foam during the manufacturing process the top of the block has a curve. This curved part increases waste as it cannot be used in any part and is removed.

In order to form smaller rectangular parts operators make use of vertical and horizontal cutting machines to reach the ordered part. These types of machines are less automated. The cutting tool is fixed and the worktable is moved manually by the operator. Furthermore, the processed part is placed and repositioned by the employee. Other more complex objects that have gradient lines on their body are processed in an angular cutting machine. This machines gives the ability for adjusting the tool in specific angle. Additionally, for complex parts that employees are unable to handle and standardize the use of CAM pantograph cutting machine is the most reliable. Thoroughly, the use of pantograph cutting machine gives a series of significant benefits related to efficiency and effectiveness. Specifically, by organizing cutting from a lean perspective waste material that arises is minimized. Furthermore the time of processing is reduced appreciably. Cutting quality, standardization and accuracy are increased. In order to use the CAM machine specialized training is necessary. For the production of sleep mattresses, inner layers are cut in another cutting machine to shape continuous curved patterns.

3.3.3 Packaging

There are two packaging tables close to the cutting machines. The one is next to the circular cutting machine which serves the packaging of mattresses and the other is next to the other cutting machines. A layer of nylon is laid on the packaging table and the produced parts are located there manually in lots by an operator. The packages are sealed then loaded on a forklift truck and they are transferred towards the exit. They stored next to the door where trucks park in order to deliver to customers. Packaging of mattresses is standardized. Packaging of Customized orders depends on the dimensions of the parts. The way they packaged is based on proper use of truck's available space and forklift truck's transferring capabilities.

3.3.4 Delivery

Managing, planning and controlling of storage space of trucks should be clear in order to optimize the use of space. Consequently, an optimized control system would reduce delivery cost. A big transporter serves the orders for the departments of Thessaloniki and Athens. There are also two smaller trucks that deliver orders in Eastern Macedonia and Thrace. A key performance indicator for efficiency could be the volume of space used per delivery route compared to the total volume of truck's storage space. Commonly the customer lead time is three days.

3.3.5 Waste material

Production and over production

As the production machine requires 1 hour for preparation and other processes to stop it is not effective to start production of blocks for a low amount. Some different qualities can produced in a sequence without stop the process. The chemical just adjusts a different recipe of polyurethane foam. Even though when some qualities of low demand are manufactured they remain as stock for a long time and cover floor space.

Waiting waste

Due to the lack of knowledge to operate the CAM machine as most of the operators except from one do not know how to use it there is high probability of queuing effect on the other cutting machines. At the same time the CAM machine operation's capacity is not deployed at an optimum level. Additionally, high workloads is possible to affect delivery customer for some orders.

Transportation waste

By observing the path that the in-processed products follow in the production area it is ascertained that transportation distance is elongated and complex. An improved path certainly reduces the risk of transportation accidents inside the industry as forklift trucks and trolleys manually handled by employees could collide. An accident affects both safety of employees and quality of products as an employee may be injured and products have defects from collapsing respectively. Particularly the longest path that needs to be redefined is the point of packaging area to point of the storage area next to the exit where trucks are loaded. It is certain that a peripheral route approaches closer to an optimized solution.

Processing waste

The manufactured blocks that have been stored for inventory need a primary cut processing to improve their quality before start being cut in the customer's ordered dimensions. The outer layer of each face, approximately 1cm in thickness, is removed as it differs in quality. Additionally, the top face of the block makes a curve that needs cutting a layer that counts on average 4 cm. After this process the cubic block develops the desired quality.

Due to the fact that the manufactured blocks have specific dimensions it is a common situation for operators to deal with customized orders made by customers which do not fit to the exterior dimensions of the block and create a significant amount of polyurethane foam waste parts that cannot be used. The way that an operator decides to handle the cutting processes of an order is based on experience. It seems that there is room for improvement concerning the organizing of the sequence of processes and give priority to the waste created aiming to the reduction of it.

Inventory waste

Above it was mentioned that the curved top of the block cannot be used for any product. The specific waste of the top is related to waste of raw material used for a part that does not add value. Based on the volume of blocks it was measured that waste of curved top reaches 4% of the whole volume. By knowing the quantity of raw materials for producing one block it was found the proportion of TDI and polyol waste of this part. To support the importance of this amount of raw material wasted it was counted the precise amount of euros were lost based on the European prices of TDI and polyols as presented in data analysis.

Motion waste

Due to the fact that the industry's surface covers approximately 4700m^2 unnecessary movement possibly causes inefficient use of time. The order that is received over the phone by office worker is passed to the operators. In some cases the customer modifies the specifications or the quantity of the ordered parts. Somebody has to transfer the information manually indicating that there is a need for direct communication between the office department and the production department that should be fulfilled. The time needed to inform about order changes is crucial and increases risk as time goes by the processing may have started and create barriers.

Furthermore, due to the lack of direct communication between operators some routes may be repeated without meaningful purpose. As an example an operator that brings to the cutting machine area a specific part from the inventory to be processed cannot be informed to load another part that is needed or make any type of change. Also, it could be a tool that is forgotten. Additionally, an employee who is available or physically closer to the desired task could handle the condition without interrupting a busy operator.

Waste of defects

It is detected that waste of defects occurs at the beginning phase of the production. Specifically, the employees load the outgoing blocks from the production line on the single axis trolley to place them at the curing area. Taking into consideration that bloc's weight reaches on average 100kg and its mass is approximately 4m^3 as well as there is the pressure of time due to the continuous flow of blocks it is a physical consequence for employees to get tired. Unconsciously, in order to make the transportation easier the employees try to place the block as close as possible to their body when they load it on the trolley in order to decrease the torque that is created due to the technical characteristics of the single axis trolley. When the block is dropped on the trolley's surface it may be pressed by the lever arm and is deformed. Due to the fact that the foam has not yet acquired its final flexible characteristics the deformation is permanent. As a consequence a deformed part needs further cut processing to remove the defective part which increases the amount of waste.

By observing the production process it was found out another type of permanent deformation but this time at the bottom surface of the block. In order to give a more visual view it is certain to indicate that there are three cylindrical components with rolling paper for maintaining the external quality of blocks. Paper prevents the detachment of foam on the walls of the extrusion part of the machine. When the outgoing block descends the conveyor to be loaded by the employee the paper at the bottom is crumpled. An employee pulls the paper to prevent the deformation of the block. It seems that the crumple of paper is caused due to the long distance between the conveyor rollers.

Additionally, there is another form of waste at the production process. When the recipe is changed during the production to manufacture a different density foam an amount of the outgoing mass has an intermediate structure which occurs due to the alteration of both chemical flow and proportion of chemicals which are included in the following quality.

3.3.6 Current layout and flow

All the processes that mentioned above are illustrated in figure … In the right side there is a caption to facilitate understanding of the layout and flow of material in the industry. Raw material are transfer through pipeline to the PUF machine. The red arrows show the path that the produced blocks follow for curing (rhomb). Yellow arrows indicate completion of curing process and directed transfer for storage. Blue arrows mark the provision of blocks ready for processing as required by customers. Finally, black arrows present the move of packaged final products collected and prepared for delivery to customers.

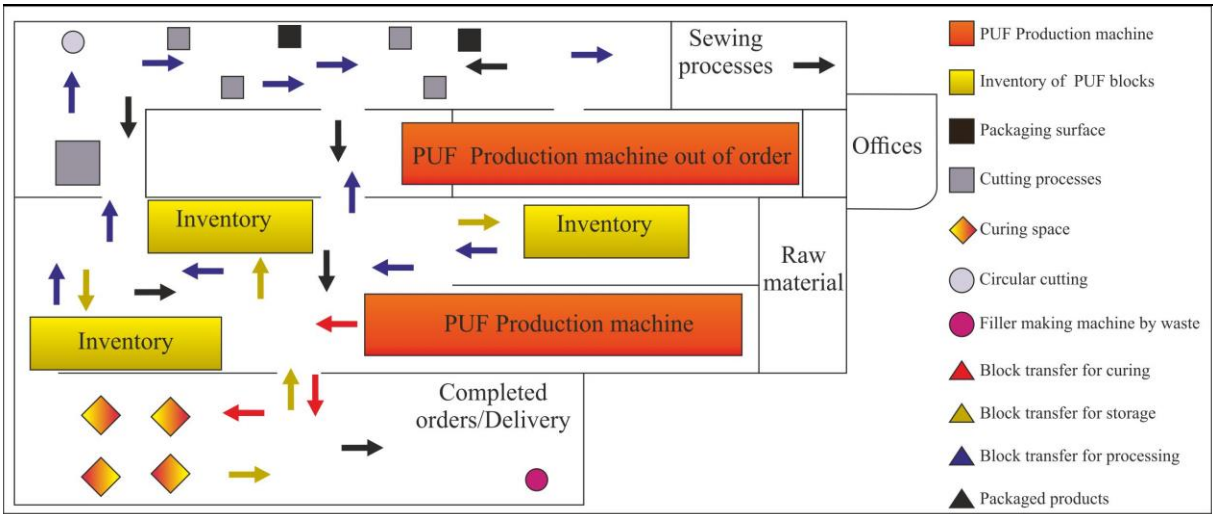

Figure 8: Current layout and flow of material.
Source (own)

Chapter 4 Redesigning-Improvements

After the identification of the company's environment and based on the available data that was possible to extract an attempt was made to measure failures, find causes of them and support results with economic evidence.

4.1 Data presentation-analysis

4.1.1 Curved top of block failure

In figure 9 it is illustrated the shape of the produced block before and after the removal of outer layer and curved top. It was found that due to the curve that is created because of the expansion of polyurethane foam during the formation of the compound, 4% of each block is wasted without counting the outer layer that is removed in order to have a homogenous qualified block for further processing. It was necessary to learn the ratio of raw materials used per block (TDI, polyols) and measure the dimensions of wasted foam to find this proportion and calculate the amount of raw material wasted for this part. The dimensions of different quality blocks differ so a mean average for dimensions was calculated after measuring the dimensions of stocked blocks for each quality. The dimensions introduced in Solidworks software to measure the mass of the whole block as long as the mass of the waste curved part.

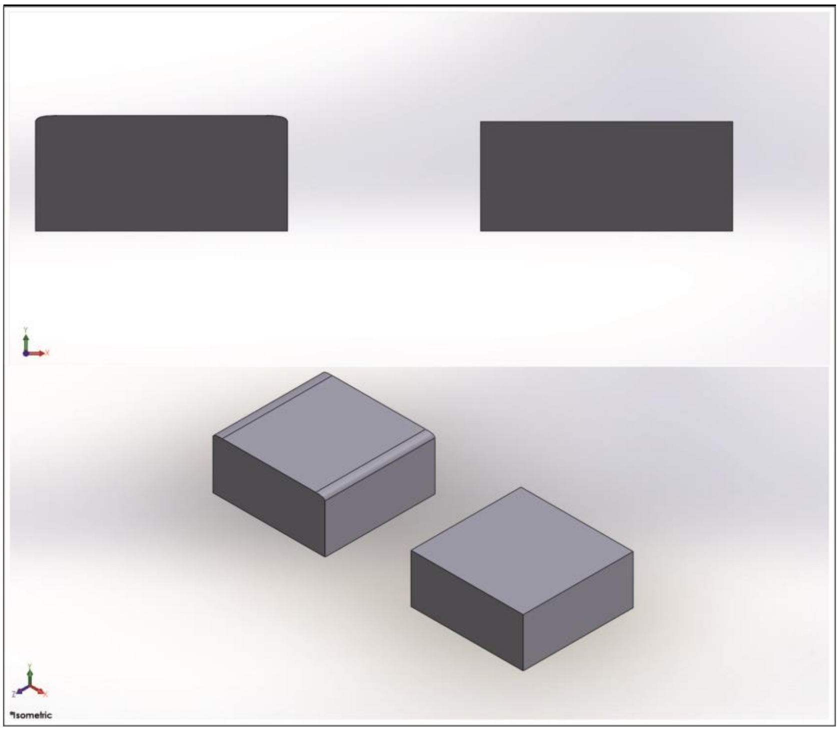

Figure 9: Front and Isometric view of Block's model before and after first cutting process

Source (own)

In table 1 the dimensions of blocks are presented categorized per type as measured in the storage space. It was also measured the distance of horizontal cutting to remove the top curve. By knowing all the dimension the blocks mass was calculated. Ina parallel using these information blocks were modeled in Solidworks in order to extract volume values of the curved part removed. For the purpose of determining and transforming waste in raw materials mean values were calculated to use them to find cost of TDI and polyols.

Kind of foam	Length(cm)	Width (cm)	Height (cm)	Final height (cm)	Volume of block (m3)	Height reduce (cm)	Volume of waste (m3)	Net volume of curved waste (m3)	Proportion waste
N25M	202	204	92	88	3,79	4	0,16	0,12	3,17%
N 25	202	204	90	85	3,71	5	0,2	0,16	4,31%
N 25Φ	220	204	93	87	4,17	6	0,26	0,22	5,27%
N 30	200	204	94	88	3,84	6	0,23	0,19	4,95%
N30M	220	204	95	89	4,26	6	0,23	0,19	4,46%
N35	200	204	99	94	4,04	5	0,2	0,16	3,96%
N 40	200	207	95	90	3,93	5	0,2	0,16	4,07%
N40M	200	207	97	92	4,02	5	0,2	0,16	3,98%
Mean value					3,97	5,25	0,21	0,17	4,27%

Table 1: Dimensional and waste characteristics of blocks

Source (own)

In figure 10 it is presented the model of produced block, the curve wasted part and the final block that is prepared for further processing.

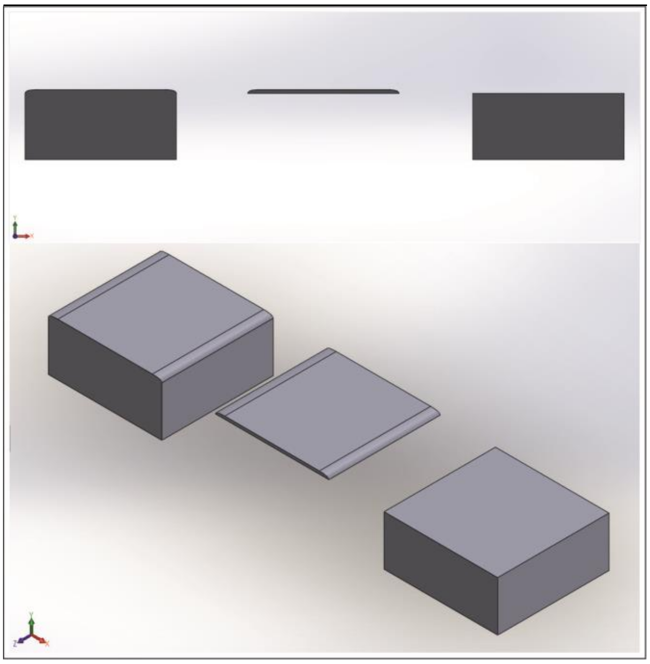

Figure 10: Right and isometric view of block and top removed

Source (own)

4.1.2 European prices of raw material in 2018

The price of TDI was doubled comparing 2018 indicator to previous years. As it is one of the basic material for producing PU foam it affects the price of the final products. Price of Toluene Isocyanate, as it can be observed in figure11, exceeded 3.20 euro per kilo in February, maximizing its price in April reaching 3.40 euro per kilo. After May it started descending periodically every month by around 0.30 euro per kilo. It reached the foregoing price nearly 1.80 euro per kilo. It was the first time in Europe the last 30 years that TDI reached so high prices due to functional problems of supplier industries and the closing of one supplier industry. As there was high demand for chemicals, this demand could not be covered by European suppliers. Additionally, it is important to mention that suppliers of chemicals are mostly multinational companies with high negotiating power. Small and medium companies struggle to get a competitive price for chemicals in comparison to big competitors that can make contracts for fixed prices of raw materials and be able to control manufacturing costs.

To be more accurate in the calculation of TDI wasted cost it was also considered, the ordering point based on the safety stock of raw material. By the moment an order is placed it takes 40 days to deliver raw material. Factors such as customs clearance and strikes in ports may affect delivery time.

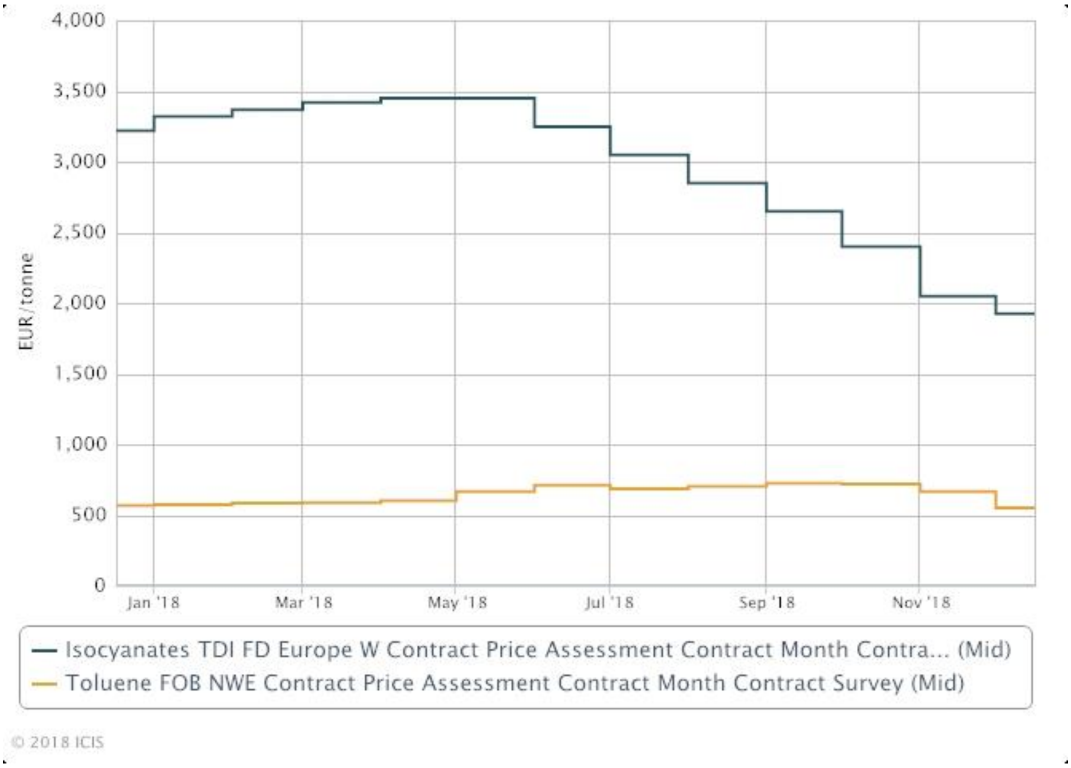

Figure 11: Fluctuation of TDI price in Europe for year 2018

Source (ICIS, 2018)

The diagram of figure 12 shows the fluctuation of the second basic raw material used for flexible polyurethane foam. The most common polyols used for manufacturing of flexible PUF are dipropylene glycol and glycerol containing less number of hydroxyl groups, two and three respectively. A specific type of polyol is used for soft foam and another one for harder foam. The price of polyols in Europe for year 2018 did not fluctuate dramatically remaining almost between 1.70 and 1.85 euro per kilo. Considering the graph of figure price of polyol was selected to be equal to 1.80 for the calculations.

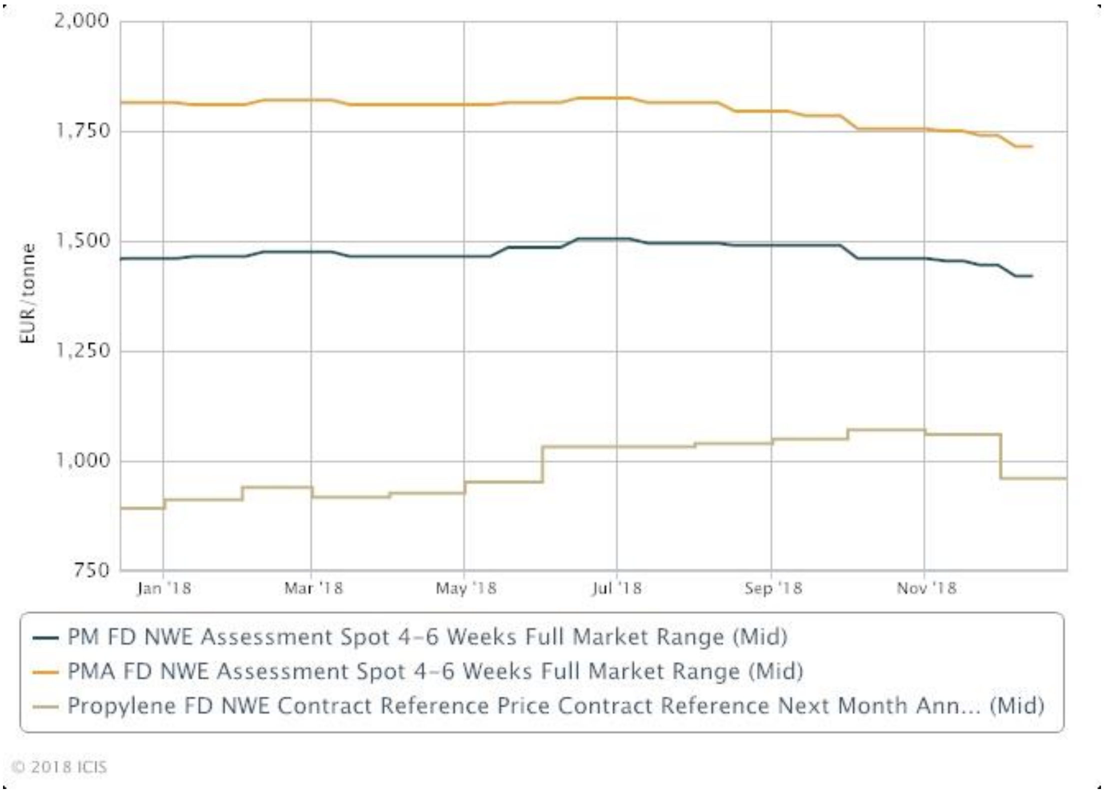

Figure 12: Fluctuation of polyol price in Europe for year 2018

Source (ICIS, 2018)

4.1.3 Cost calculation of raw material waste

By knowing the volume of produced foam per month as well as the consumption of raw materials it was found the required amount of TDI and polyol required per cubic meter. Additionally it was calculated the volume of wasted foam and converted to raw material waste. As the prices of raw material are calculated in kilos and the data that elicited are measured in kilos it was necessary to find the density of TDI and polyols to calculate the final cost.

Months of year 2018	Consumption of TDI per m3 of PUF	Volume of wasted PUF (m3)	TDI wasted (m3)	TDI's weight (kg)	Cost of TDI (euro)	Volume of block
January	0,009	80,436	0,715	864,617	2.593,85 €	3,95 m^3
February	0,009	37,757	0,334	403,693	1.291,82 €	**Volume of waste/block**
March	0,009	77,283	0,693	838,136	2.765,85 €	0,17 m^3
April	0,008	38,803	0,326	394,293	1.340,60 €	**Density of TDI**
May	0,009	67,432	0,608	735,104	2.499,35 €	1,21 kg/l
June	0,009	57,331	0,498	601,998	1.926,39 €	
July	0,008	101,927	0,857	1037,160	3.215,20 €	
August	0,009	37,064	0,319	385,831	1.196,08 €	
September	0,009	40,064	0,365	442,140	1.237,99 €	
October	0,009	70,518	0,631	763,902	1.986,15 €	
November	0,008	38,239	0,320	387,752	930,61 €	
December	0,009	75,118	0,659	796,793	1.673,27 €	
Summary		721,973	6,323	7651,420	22.657,14 €	

Table 2: Calculating waste cost of TDI

Source (own)

Months of year 2018	Consumption of polyols per m3 of PUF	Volume of wasted PUF (m3)	Polyols wasted (m3)	Polyol's weight (kg)	Cost of polyol (euro)	Volume of block
January	0,017	80,436	1,398	1439,654	2.591,38 €	3,95
February	0,020	37,757	0,739	761,175	1.370,12 €	**Volume of waste/block**
March	0,020	77,283	1,550	1596,203	2.873,16 €	0,17
April	0,016	38,803	0,635	654,253	1.177,66 €	**Density of polyol**
May	0,019	67,432	1,288	1326,327	2.387,39 €	1,03 kg/l
June	0,018	57,331	1,018	1048,206	1.886,77 €	
July	0,018	101,927	1,806	1860,298	3.348,54 €	
August	0,019	37,064	0,718	739,809	1.331,66 €	
September	0,020	40,064	0,795	819,255	1.474,66 €	
October	0,020	70,518	1,412	1454,438	2.617,99 €	
November	0,017	38,239	0,639	658,132	1.184,64 €	
December	0,019	75,118	1,458	1501,791	2.703,22 €	
Summary	0,018637636	721,973	13,456	13859,542	24.947,18 €	

Table 3: Calculating waste cost of polyols

Source (own)

4.1.4 Trolley material failure

Due to physical fatigue of employees as well as the characteristics of the trolley used for block transferring from the end of the conveyor to the curing area some blocks are deformed permanently. Specifically, when the block is loaded on the one axis trolley it falls towards the handling leverage and compressed. The following figure provides a 3D model of the trolley that is used and the deformation of the block. As a key performance indicator it would be the number of blocks that deform per production day. In figure 13 it is rendered the model of the trolley used for the transferring of blocks as well as the falling of block on the leverage that deforms permanently the block.

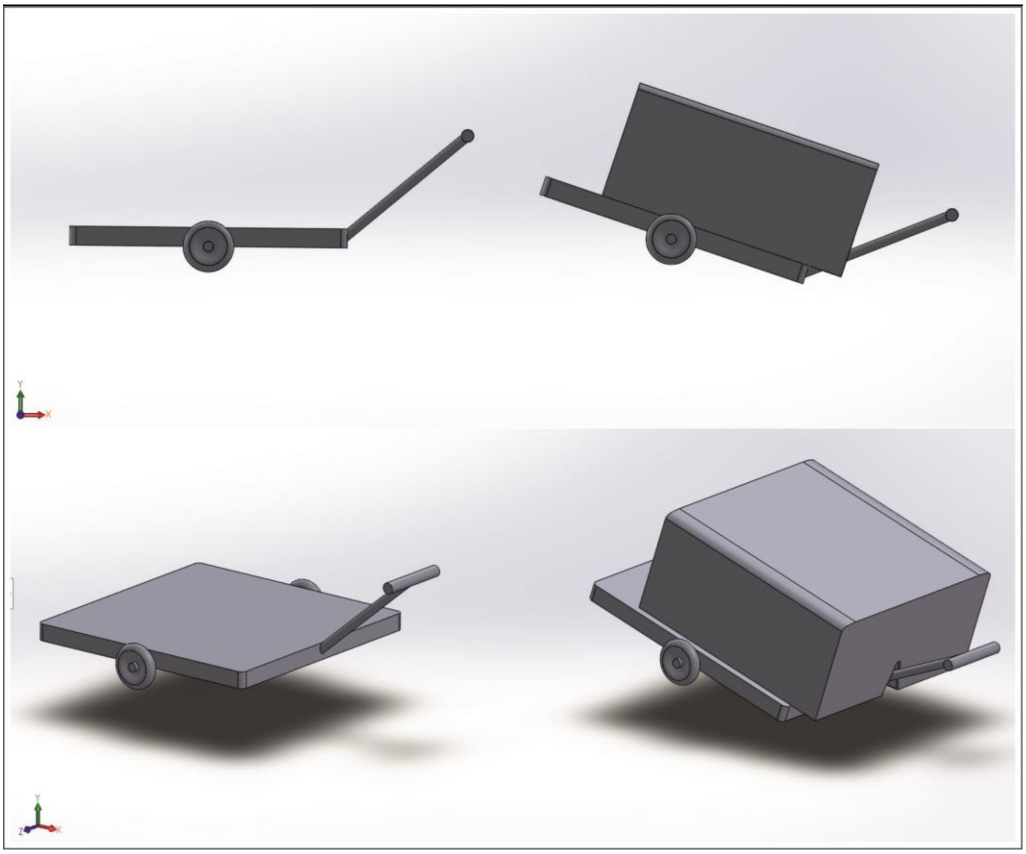

Figure 13: Right and isometric view of trolley and loaded block

Source (own)

This deformation contributes to the creation of foam waste. When the time comes to process this part the operator decides how to handle it in order to fit it in the desired dimensions of the ordered part. If it does not fit it stays in stock for another order. Additionally keeping waste of this part at low levels depends on the operators experience, envisioning and computational skills.

4.2 Results and recommendations

Although that at first glance a percentage of 4% of waste seems low and not important. Considering that price of TDI was fluctuating and high, price of polyols was constant it calculated that cost of TDI waste for year 2018 reached 22.657,14 euros. Additionally, the cost of polyols wasted computed that reached 24.947,18 euros.

Figure 14 presents the current model of the machine plant. In order to improve the shape of manufactured block aiming to save raw material and increase its quality it is proposed the addition of some parts in the existing machine as it is presented in figure 15. By installing horizontal turning cylinders at the top of the flowing tunnel on specific spots the top face will be squared shaped. It is important to highlight that paper is added at the top such as both at right and left side of block. In more detail, the aim of adding the cylinders is not to press the block. In its expansion it won's take the shape of swelling bread. It should expand towards the corners too by interfering in flow of raw materials as it is still liquid at the expansion process.

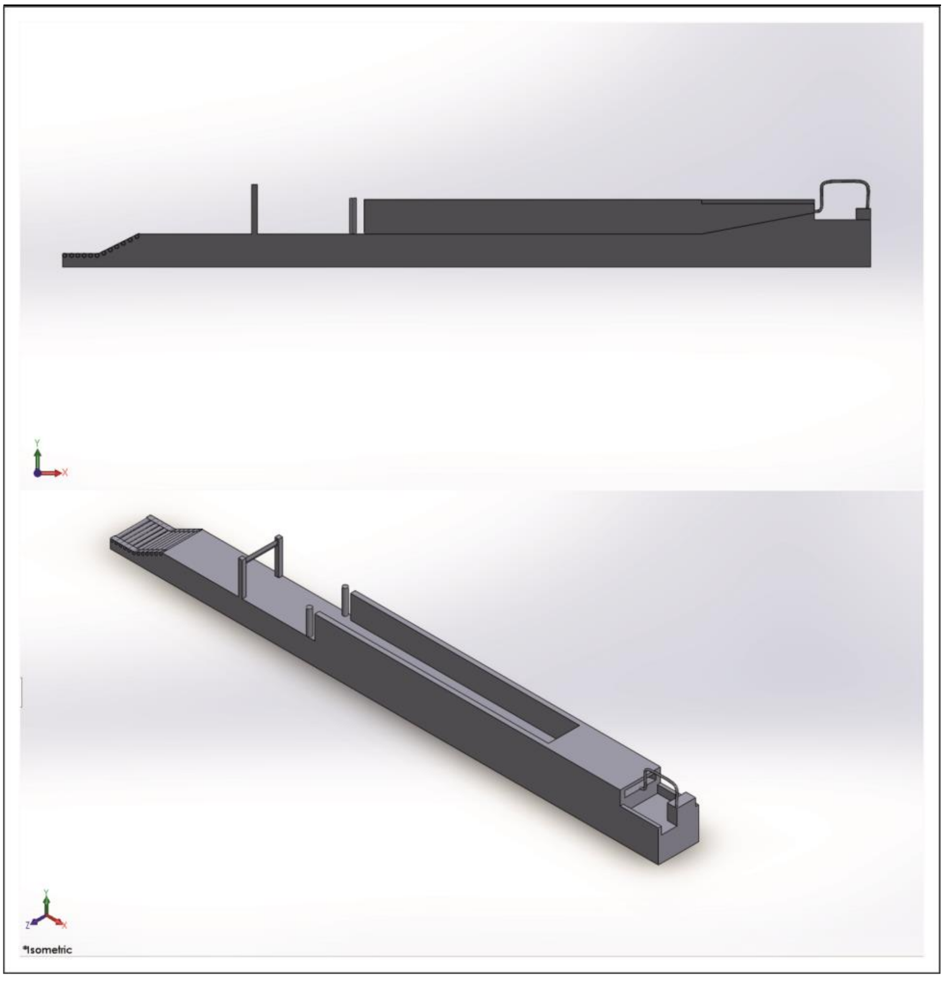

Figure 14: Current model of machine

Source (own)

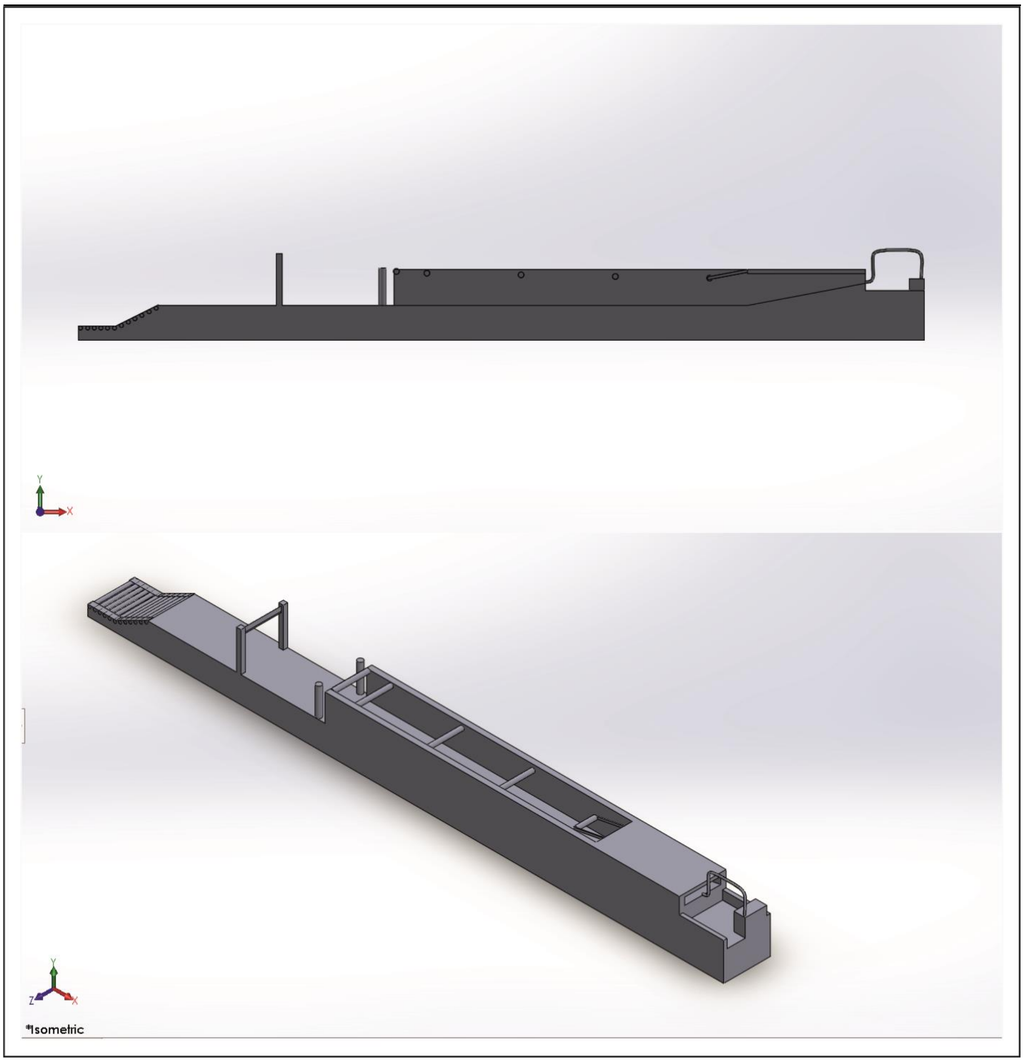

Figure 15: Addition of rollers on the top part of machine

Source (own)

Furthermore, another proposal for the avoidance of block's bottom deformation due to the wrinkling of paper it could be the addition of more horizontal cylinders at the end of the machine. The rolling of block becomes smoother and deformation is prevented increasing quality. Besides quality, there is no need for operator standing by the block that is loaded on the trolley to remove the bottom paper. By this improvement the operator is released of this process and becomes available for another.

The possibility for block deformation during loading of blocks to trolley at the production stage increases due to the physical fatigue of employees. In order to eliminate this risk that results in decrease of quality, creation of waste and considerations about the way these blocks should be handled it is proposed the improved trolley of figure 16. By adding a rectangle wooden piece at the edge of the trolley's loading surface the block is impeded to fall on the leverage and be deformed.

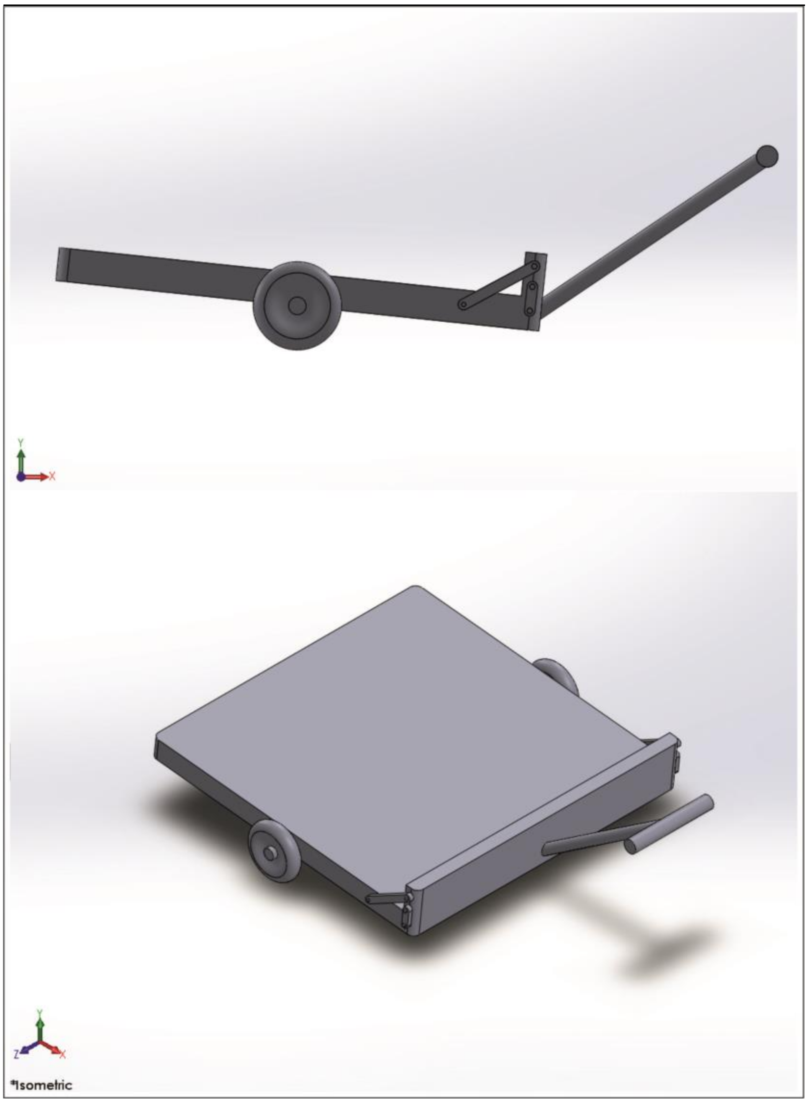

Figure 16: Views of improved trolley

Source (own)

Considering the whole layout of the industry aiming to reduce production, waiting, transportation and motion waste a new layout is proposed as presented in figure 17. The proposal is based on the types of waste found at the observation stage and they were mentioned in subchapter 3.3.5 page 14. To facilitate the comprehension of the processes there has been made a caption at the right side of the proposed layout.

In the new layout the old machine is replaced with a new production machine that manufactures via the use of block molding. By this way there is no need for keeping stock for special qualities with low demand. The red arrows showing the path of manufactured blocks that are transferred for curing. Yellow arrow presenting the transferring of cured blocks to stock, the blue arrows represent the processed products and the black the final packaged products.

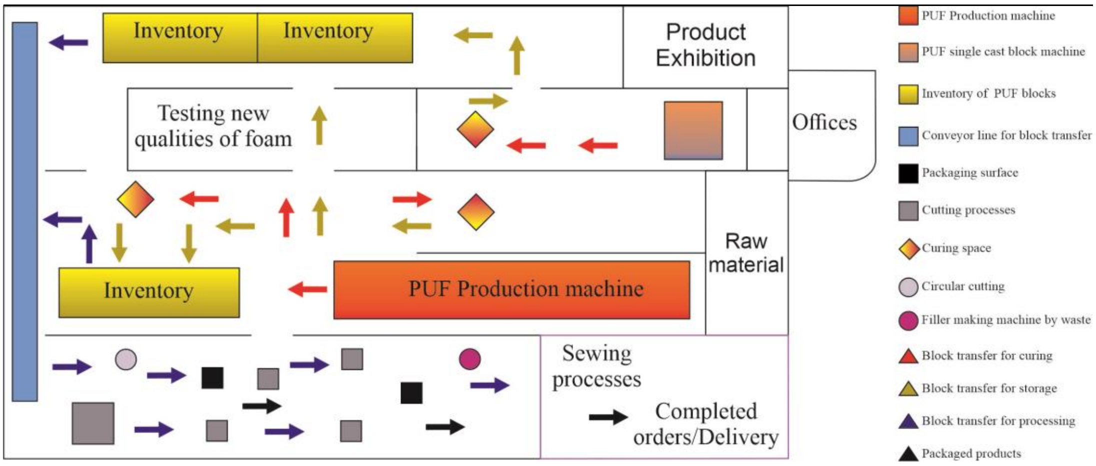

Figure 17: Improved layout and flow

Source (own)

After curing they move to the inventory. By adding a conveyor line connecting inventory to cutting processes department it is eliminated the move of forklift truck in the heart of the industry preventing safety issues and reducing time of transformation. Relocating the cutting processes as well as the sewing processes close to the exit were completed orders loaded for delivery it is reduced a significant number of moves inside the industry. The prior sewing processes department becomes the "Product exhibition" department were samples of final products are exhibited for the customers. Furthermore, as there is possibility for producing single blocks of different quality, a department for testing new qualities of foam next to the new machine gives a competitive advantage to improve quality of foam. The new machine gives the opportunity to expand in a new market field besides flexible polyurethane foam products and manufacture polyester foam products.

Additionally, wasted foam of cutting processes remains at the processing area, collected and introduced into the filler machine and packaged as a product. Concerning inventory control it should introduced a bar code system integrated in the ERP system. Besides, training of employees for efficient cutting as well as for CAM software and lean principles should be introduced as a formal activity. Another proposal for reducing time and motion waste of employees is related with communication issues due to the area size of the industry. Intercommunication between employees improves the working efficiency. It could be solved by providing VHF wireless transceivers to the employees and the offices. Unnecessary move of office employees and operators prevention releases time that could be used for training of employees.

Due to the fact that commercial final products have more value than semifinal products it should be seriously considered to produce mattresses pillows and other products addressed for sectors related to clinical products and hospitality.
Another factor that affects costs of production is energy consumption for keeping temperature of raw material constant at 25^{o}C. As it is presented in the layout the area of raw material storage should be reduced as there is no need for keeping temperature constant for the whole room. The room's volume should be halved in order to reduce the consumption of electricity for cooling or heating.
Prioritization of improvements is based on cost, easiness of application and time utilization. Furthermore, changes follow a sequence that does not affect industry's operations in a way that influences operations.

Prioritizing improvements

1. Improving trolley
2. Intercommunication devices
3. Adding extra rollers in the production machine
4. Adding top cylinders in the production machine
5. Introducing electronic inventory control
6. Training of employees for efficient/special cutting
7. Buy the new block molding machine
8. Buying of conveyor line
9. Build the new area of sewing department
10. Creating product exhibition department
11. New product development department/Testing new qualities
12. Change the whole layout.

Chapter 5 Conclusion

5.1 Limitations

In order to identify specific spots for introducing cylinders on the top of machine it is required to analyze the phases of foam's expansion. Regarding the block deformation caused by trolley's leverage it was not possible to measure the rate of defects as there were not sufficient number of tests during the production phase. Furthermore, suggesting specific layout for cutting machines needs more circumstantial observation for a long period as the products are customized and produced with make to order strategy. Lack of time was a limitation that could not be surpassed.

5.2 Future work

The specific case study could be proceeded in order to synchronize the use of cutting machines. A techno-economic analysis in relation to energy efficiency could be conducted from an engineer perspective. By knowing the energy consumption it would have interest to examine the possibility for energy autonomy, possibility to produce electricity for the company's needs and reduce the energy consumption of raw material space. Additionally, the reconsideration of marketing plan along with the sales strategy, the company's core values, the division of labor and the possibility for adding more shifts and hiring new specialized employees should be studied in deep. The future objective aims to reinforce business activity and support the propositions of the presented dissertation's outcome in order to make it feasible.

References