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Application of Lean Manufacturing Methods to a Marble Factory

by

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Dissertation submitted in partial fulfilment for the Degree of Master of Science in Engineering Business Management, WMG, University of Warwick

Supervised by Dr. Susan Grinsted

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Abstract

Lean manufacturing originates from the concept of identifying value in an organisation to minimise the non-value-adding activities, and thus reducing waste of time and resources. In today's world, lean is utilised by countless organisations from different industries all around the world. This research aims to find the possible outcomes of implementing lean manufacturing techniques and ways to reduce wastes in a marble processing factory in Antalya, Turkey. Every process in the factory was analysed and lean tools such as VSM, Kanban, Kaizen, 5S workplace organisation, multi-functional teams, and work cells were utilised to reduce wastes in production. It was found that the factory had issues in holding large amounts of inventory, developing a variety of products, and having a disorganised stock area. The lean tools were applied to eliminate these wastes, and an implementation plan for the factory was presented. According to the findings of this research, lean implementation reduced block production lead-time by 15%, and rubble production lead-time by 50%. It was also found to be safer than the previous method and thus predicted to decrease defects in production and have cost benefits in the future. Nevertheless, the marble industry also limits the application of lean since holding inventory was found to be crucial to the business. Accordingly, application of lean techniques to the marble industry are limited, however it is still possible and feasible to implement some of the lean tools in order to reduce wastes in marble production.

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I would finally like to thank my girlfriend Elif, because of her support and confidence in me.

Declaration

I have read and understood the rules on cheating, plagiarism and appropriate referencing as outlined in my handbook and I declare that the work contained in this assignment is my own, unless otherwise acknowledged.

No substantial part of the work submitted here has also been submitted by me in other assessments for this or previous degree courses, and I acknowledge that if this has been done an appropriate reduction in the mark I might otherwise have received will be made.

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Project definition for my degree (as copied from http://www2.warwick.ac.uk/fac/sci/wmg/globalcontent/general/project/requirement/)

The project should normally be related to the management of:

1. companies in the engineering sector,
2. the engineering function within a non-engineering company *or*
3. the supply chain within the engineering sector.

The project could address many different aspects such as operational, financial, human resource, technical or strategic management issues.

Where the project is of a technical nature, there must be clear evidence of business benefit from this technology.

If the focus of the project is outside the above industrial spectrum it MUST contain considerable comparative analysis of practices in the engineering sector.

My project relates to this definition in the following way:

As a student of Engineering Business Management, the project is set on a manufacturing company that uses engineering processes in extracting and treating marbles. So, this project is going to be on the management of manufacturing processes that a marble goes through. I have the opportunity to collect data for engineering processes from this company since it is our family business.

The case company in this dissertation is owned by my family, so this research is an opportunity for me to engage in the business and learn more about the field. The case company owns a factory for processing marbles, which includes engineering processes that are explained in detail in this dissertation. This project relates to operational, financial, and some strategic management issues in the company. The outcomes of this project suggest the feasibility of lean manufacturing methods in the marble industry and thus creates a new understanding in this area since there is a lack of information in the literature.

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1 Introduction

1.1 Broad view of the general research area

Lean Manufacturing techniques have shown to generate considerable benefits to companies from different kinds of industries all around the world. Although it was initially shaped for the automotive industry, many other companies have implemented lean in order to gain benefits from reducing costs, reducing lead-times, increasing customer satisfaction, reducing inventory, reducing defects and numerous other benefits. Nonetheless, the implementation of lean manufacturing to the marble industry appears to be non-existent in literature. Consequently, this research was conducted in order to gain knowledge about the possible benefits of a lean implementation to a marble processing factory.

1.2 The Research Outline

1.2.1 Project Definition

This project is aimed at utilising Lean Manufacturing methods, and ways to work more efficiently in the manufacturing processes of a marble mining and treating factory located in Antalya, Turkey. The first stage of this project is to construct a literature review for working more efficiently and reducing wastes and costs in a factory (Lean Manufacturing). The research will be based on the manufacturing processes that a marble goes through starting from getting extracted from the mountain until they are shipped to the customer. Accordingly, time and waste management is going to be analysed on these processes.

1.2.2 General Background

This project was planned and executed by the author of this dissertation whose family business is the marble factory in Turkey which is the subject of this project. Previous to deciding to investigate lean manufacturing, a brief diagnosis of the factory was given by the CEO of the organisation. The business essentially was formed of two distinctive productions which are extracting the stones from the mountain and processing them. Extracting marbles were found to be more accurate and defined rather than the factory where the marbles are cut to size and processed. There were some flaws in the factory regarding excess inventory, scheduling and time management. Also, extracting stones is more similar to the construction industry rather than manufacturing. Thus, with the rise in popularity of lean manufacturing in the recent years, it was proposed that lean manufacturing techniques could be utilised in order to aid and optimise the factory.

Lean Manufacturing is a management philosophy derived from the 'Toyota Production System', and it is a way of managing and reducing the wastes in manufacturing processes (Karlsson and Ahlstrom, 1996). The main idea beneath lean manufacturing is to eliminate the things that are not adding value to the organization. These changes can be made to logistics, production, inventory, scheduling, etc. By reducing wastes in the working environment and optimising production using lean tools, improved processes can add value to the product and thus increase productivity and even profitability.

During the beginning phase of the project, the CEO of the factory gave a brief explanation of the problems namely; the surplus inventory, challenges in production, and setbacks in production planning. Moreover, the company seems to have issues with the inventory restricting the workspace available in the factory. A suitable management of these processes should increase production efficiency, since it allows to increase the output from the production. Other related lean manufacturing methods could be applied to the associated manufacturing processes going through the factory.

1.2.3 Purpose

The main benefits of this research are expected to be as depicted below;

- Reducing lead-times by re-scheduling
- Reducing inventory, inventory management
- Reducing wastes in the production processes, thus increasing productivity
- Reducing waiting times
- Increasing delivery-on-time and customer satisfaction
- Increasing the overall efficiency of marble extraction and production, increasing profitability

These outcomes are both connected with lean-manufacturing and the actual issues in the marble factory. The benefits that can be achieved by this research is going to be in a theoretical level, and accordingly they can be useful to implement them to the real factory. The key strategy is to organize an optimal production plan and layout for processes, and an ideal schedule to work in the most efficient and cost-effective way possible.

1.2.4 Guiding Questions

The main research question for this marble company is:

- What are the ways to reduce wastes in the marble factory?

And this question can be broken down to guiding questions such as:

- What are the main wastes in manufacturing?
- Is there any way to decrease production lead-times?
- What processes are the bottlenecks?
- What are the schedules for production planning?
- Is time management relevant to the manufacturing processes?
- Is the process layout suitable for working in the most efficient way?
- Are there any other ways to use inventory in a more effective way?

1.2.5 Objectives

The main objectives for this project can be simplified to:

- Diagnosis of the factory for each process
- Analysis of the data on waste
- Development of lean methods to the factory where applicable
- Proposal for the factory manager

1.2.6 Action Plan

The action plan for this project can be put in to 3 different stages. The initial stage consists of a detailed literature review on waste management and Lean Manufacturing so that there is a basis on analysing data. Later on, there will be a diagnosis of the company for managing time and costs, which will lead to an analysis of the data taken from the factory managers. The analysis will be constructed based on the literature review on Lean Manufacturing. Subsequently, a production management schedule will be examined with the data collected from the analysis. Finally, a proposal for the factory managers will be offered regarding all of the conclusions made on waste management.

1.2.7 Contribution

The outcomes the author wishes to gain from this project are firstly assisting the business gain a competitive advantage in the market and add value to the business. This is essential because it is the main objective that is desired to achieve by the end of this project. Additionally, the author expects to gain experience in management of engineering processes in a company, so that he can utilize the knowledge he gained in his own career. Since this factory is owned by the author's family, he hopes to help in managing the factory in the future, so this is an opportunity for the author to advance his career in the right way whilst serving the business.

2 Literature Review

The literature review chapter of this dissertation will consist of the core principles and concepts regarding lean manufacturing. The purpose of this literature review is to gain awareness on the subject and the possible applications to be able to evaluate the application of lean in the marble industry.

2.1 Introduction to Lean Manufacturing

The lean manufacturing concept originates from Japan, more specifically the Toyota Production System (TPS). After the Second World War Toyota Motor Company developed the lean philosophy in order to reduce costs and be more competitive in the world (Karlsson and Ahlstrom, 1996). The first implementation of lean principles can be seen in TPS, although the first authors to introduce lean manufacturing to the West are seen as; Robert Hall (1983) with his book 'Zero Inventories' establishing a lean tool called just-in-time (JIT), whereas the term lean was first used by Womack and Jones (1991, 1996) with their well-established book 'The machine that changed the world: the story of lean production'. Additionally, JIT and TPS were introduced by Monden (1983) and Ohno (1979) with the inclusion of Schonberger (1982) and Sugimori *et al.* (1977) on Japanese manufacturing techniques. Womack and Jones (1991) suggested that TPS was far ahead in performance measures compared to other organisations in the automotive industry, and thus coined the term **lean thinking** referring to TPS style production and management systems. Lean Manufacturing is commonly seen from two different perspectives; a practical tool as a managerial practice (Shah and Ward, 2003; Sugimori *et al.*, 1977), and a philosophical tool as a set of funnelling principles and superior goals (Womack and Jones, 1991,1996; Spear and Bowen, 1999; Barker, 1994). The key elements and fundamental themes of lean will be explained below to develop a more enhanced view.

2.2 Value

The definition of value in lean manufacturing differs from traditional manufacturing in the sense that it is described as being perceived from the customer's perspective. Traditional manufacturing methods usually define value from the organization's point of view, which emphasizes that value is only important inside the company. However, identifying value from the customer's perspective in lean manufacturing results in making the flow align with the customer's pull, and thus creates a flow in the supply chain by introducing this connection between the supplier and customer.

The main model of lean manufacturing originates from this identification of value, since it is essential to eliminate what doesn't add value. Taiichi Ohno (1988), who is considered to be the father of the TPS, portrayed this non-value adding activities as 'Muda' which translates to 'waste'. In this sense, wastes are those activities which don't add value from the customer's perspective and thus should be eliminated. According to Taiichi Ohno (1988) there are seven types of wastes that are essential to eliminate in order to achieve a lean state in an organisation. The types of wastes will be explained later in section 2.4.

2.3 Stages of Lean Thinking

Figure 1 - The five lean principles

According to Womack and Jones (1996), there are five stages to lean thinking which are: recognizing value, identifying the value stream, creating flow, letting the customer pull, and finally perfection (see fig. 1). This process starts with (1) recognising value, which can be identified as any activity or service that adds significance and usefulness to the customer. Then comes the (2) identification of the value stream, also called value mapping, which consists of the set of actions necessary to bring a product to the customer such as design, engineering, manufacturing, and delivery. Any wastes found in these processes must be eliminated. Correspondingly, a current and future state of the value streams can be mapped in order to identify any wastes in both circumstances and eliminate the current wastes and develop a plan to minimise wastes in the future. After value mapping, comes (3) the creation of flow in the company, which means making the previous steps flow in smaller pieces and removing functional barriers in order to reduce lead-times. And once the flow is achieved, the demand is based on (4) the customer's pull. This also makes demand forecasting irrelevant, since the demand is set to be in small batches which similarly reduces the need for inventory. Once all of these steps are attained, the last step becomes (5) perfection of the system. This isn't an end of the lean process but rather perfection implies the continuous improvement of each stage to form a product even more close to the customer's expectations. In fact, the model of the stages of lean manufacturing is rather a cycle than a linear process. This way after the last step comes the first stage and perfection is achieved if the product is exactly what the customer requires with no wastes in the manufacturing processes.

2.4 Classification of Wastes

Figure 2 - Levels of Waste (Muda)

Wastes are categorised as value adding, type 1 and type 2 mudas according to Womack and Jones (1996) (see fig. 2). The value adding activities are defined as wastes that create or add value from the customer's perspective. These wastes can consist of activities such as brainstorming or research and development where many solutions are discussed but only a single solution remains after the decision is made. Type 1 Muda consists of activities that don't essentially add value to the customer but are necessary, such as inspections and safety examinations. Type 2 Muda are activities that are non-value adding and redundant for the customer. This results in eliminating the type 2 Muda. Nevertheless, this doesn't mean that the aim is to remove only the type 2 Muda, but rather to establish a system with continuous improvement in order to have no wastes.

Figure 3 - 3 Broad types of Waste

The initial types of waste were classified in three parts identified by the Toyota Production System (Ohno, 1988) (see fig. 3). (1) Muda has two types and was discussed above. (2) Mura, meaning unevenness, is the reason behind Muda. Mura can also mean irregularity and non-uniformity, and can happen by having different work capacities over different production lines or processes. This will result in having dissimilar outputs which consequences in overproduction or waiting. (3) Muri, meaning overburden, can result from Mura or the unsuccessful elimination of Muda. Muri exists when employees or machines are utilised more than their capabilities. This creates an unsustainable environment and can result in machine breakdowns and unhealthy employees. In order to get rid of Muri, standardisation of resource based tasks can be utilised.

It can be inferred that these three classifications are interrelated, and when one is eliminated the other one can show up. Having Mura in a process can lead to Muda, and trying to eliminate the Muda can result in Muri. To connect this relationship, Muri concentrates on the planning of a process and what can be avoided by a better design for the process. Mura then focuses on how this process design is implemented in the factory and eliminating variations in the operational level. Muda is then exposed when the processes are in place and should be dealt with continuously. However, when dealing with Muda it is important to balance the relationship of Mura and Muri. Type 2 Muda is then categorised in to 7 levels of waste.

2.5 Bottlenecks

A bottleneck is the process that has the lowest capacity, or the output/input ratio which therefore limits the capacity of the entire production. Consequently, this causes delays along the succeeding processes, overloads machinery and employees, creates supply overstock, and disrupts and stalls the stream of production. Recognising bottlenecks are crucial for increasing the total throughput of production (Goldratt, 1984). Goldratt (1984) argues that the bottlenecks are always struggling to keep up even though they are the ones that are fully utilised, which makes them seem like they are efficient processes. A bottleneck can be an equipment, a person, a computer, a department, or even an entire work station. Since bottlenecks are the processes that limit the maximum throughput, allocating more resources to them will therefore increase the rate of production. It is also important to recognise that allocating more resources to a bottleneck doesn't indicate that the bottleneck is fixed, but rather it shifts to another process in production that has the least output/input ratio.

Lean manufacturing principles could be an effective way to reduce the occurrence of bottlenecks, and improve the complete production stream by reducing inventory and materials related problems.

2.6 7 (+1) Types of Waste

The seven types of wastes were developed by Taiichi Ohno (1988) and then the last one below was introduced by Womack and Jones (1996). Accordingly, the 7(+1) wastes (type 2 Muda) are:

- Unnecessary transportation of products
  - Unnecessary transportation increases throughput time and work-in-progress inventory level
- High levels of inventory (any level higher than the absolute minimum)
  - High levels of inventory take up valuable workspace in the factory and clogs newly produced products, causing bottlenecks in the production plan.
- Unnecessary motion or movement of people
  - Unnecessary movement causes reduction of man time which leads to underutilization of man power.
- Overproducing
  - Overproducing ahead of demand causes excess inventory.
- Defects
  - When defects increase in production, resource utilisation declines. This leads to a decrease in machine and man time.
- Waiting (for the next production process)
  - Waiting for the next process creates bottlenecks in production and increases WIP inventory.
- Over processing of parts due to bad design
  - Over processing leads to waste of time. Hence, continuous improvement of the design is crucial in order to avoid it.
- Not meeting customer's requirements
  - Value in lean is defined by the customer, thus anything in production that is non-value-adding is considered waste.

These typical wastes in production are essential parts of diagnosing a manufacturing plant. Taiichi Ohno's 7(+1) wastes will be considered as a guideline when analysing the factory in the analysis part of this dissertation.

2.7 The 4 Rules of Lean

Spear and Bowen (1999) introduced four rules in order to capture the knowledge and base understanding of the Toyota Production System. These rules are:

1. Every work and process must be highly specified as to content, sequence, timing, and outcome
2. Supplier-customer relations must be direct and there must exist a straightforward 'yes-or-no' way for requests and responses
3. Every product's route must be simple and through
4. Improvements must be made according to the scientific method and with a supervisor, starting at the lowest possible level in the organisation

Activities, tasks, connections and flow paths with these rules require some built-in testing systems to signal problems before they occur. This creates a feedback mechanism for the system and thus rely on the continuous improvement of each and every aspect of tasks. Thus, lean manufacturing becomes more of a flexible and adaptive system rather than being a set of rules.

According to Spear and Bowen (1999), lean manufacturing relies to these four rules for successful implementation. Nonetheless, in the operational level, these rules should be perceived from the employee's perspectives. That is why Spear and Bowen (1999) portray these rules as questions of supervisors to the operational employees in the form:

- How do you do this work?
- How do you know you are doing this work correctly?
- How do you know the output is going to be free of defects?
- What do you do if you have a problem?

2.8 Steps to achieve Lean

In order to accomplish a lean production system such as TPS, the main initiatives are (Akinlawon, 2008; Barker, 1994; Sugimori *et al.*, 1977; Karlsson and Ahlstrom, 1996; Krafcik, 1988):

- Designing a simple manufacturing system
- Acknowledging that there is always room for improvement and higher efficiency
- Continuously improving the system design

Since the fundamental principle of lean manufacturing is the customer-pull mechanism which enables the flow of the lean processes in production; designing a simple system could have benefits like:

- Less inventory

- Increased resource productivity
- Increased machine and equipment utilisation
- Decreased cycle time

2.9 Lean Manufacturing Definition by Author

Table 1 – Definitions of Lean by author

Author	Definition
Krafcik (1988)	Compared to traditional manufacturing it uses less of everything, half the human effort, production space, tools, engineering hours, in half the time. Also uses less than half the inventory, while resulting in less defects with a high variety of products.
Womack and Jones (1991)	Coined the term 'lean' for TPS like manufacturing techniques that involve minimal inventory. Lean is a dynamic process of change with a systematic set of principles and best practices aimed at continuous improvement.
Hayes and Pisano (1994)	Lean uses less, or the minimum, of everything required to produce a product or a service.
Oliver *et al.* (1996)	Lean producers are characterised by just-in-time production, small lot sizes, and minimal inventories.
Liker (1996)	Lean is a philosophy that reduces the time from customer order to delivery by eliminating sources of waste in the production flow.
Cox and Blackstone (1998)	Lean is minimisation of all resources. Involves identifying non-value adding activities in design, production, and supply chain.
Shah and Ward (2003)	An integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability. It combines interrelated elements like just-in-time, quality control systems, multifunctional teams, cellular manufacturing, and likewise.

As seen in table 1, lean manufacturing has been defined by various authors through the years. It can be inferred that there is a common understanding in literature that lean production uses less or minimalised resources to achieve the same or even less defected output. Lean achieves these outcomes by using various lean methods and tools. For this reason, regarding this dissertation, lean is seen as a 'dynamic process of change with a systematic set of principles and best practises aimed at continuous improvement' (Womack and Jones, 1991). Therefore, in this project's context, lean manufacturing is also perceived as being the tools and techniques it commonly uses.

2.10 Lean Manufacturing Tools

Lean manufacturing's main purpose is to discover superior ways to do things that require less time, effort while using fewer resources. This is done through the practice of different lean tools. Lean manufacturing contains numerous tools that varies for each industry and application. Bicheno (2004) argues that certain lean tools may be more suitable for one business than another. Some of these tools are Value Stream Mapping (VSM), Just-in-time (JIT), Kanban, 5S, Cellular Manufacturing/GT, Poka Yoke, Supplier Relationship, Visual Control (Andon), Standardized Work, Simulation, Automation (Jidoka), Kaizen, Single-Minute Exchange of Die (SMED), Total Quality Management (TQM), Production smoothing (Heijunka), Total Productive Maintenance (TPM), PDCA (plan, do, check, act), Key Performance Indicators(KPIs), Root Cause Analysis (Ishikawa Diagrams), Takt Time, Bottleneck Analysis (Sangwan, 2014; Rother and Shook (1999); Spear and Bowen, 1999; Sugimori *et al.*, 1977; Karlsson & Ahlstrom, 1996). The most commonly used tools and their descriptions are provided in Table 2.

Out of all the provided tools, some are more relevant to the marble industry. Besides, there was no prior experience and training on lean methods in the case factory, thus the tools that will be chosen in context of this project will be the ones that can be applied by the researcher on its own. Therefore, the tools that are applied in this dissertation will demonstrate what benefits there could be as a starting point and for further implementation at a later date. The tools that look most feasible are VSM, JIT, 5S, Kanban, multi-functional teams and U-line, Ishikawa Diagrams. VSM is a tool that reveals wastes in the existing processes for the factory and moreover delivers a plan for improvement. It is also a visual tool to help understand the processes more simply and clearly, therefore is fundamental for this project. JIT is successful in lowering inventory levels, and as a consequence improves the workspace environment. This relates to one of the major problems regarding the case factory. 5S is an effective tool for organising the work area in the operational level, and it eliminates waste that results from looking for an item. Unlike most of the tools, 5S can be implemented on the shop floor for the case factory and consequently is indispensable for the project. Kanban is a tool that eliminates waste from inventory in the shop floor and can reduce the need for physical stocks. Kanban is also a viable tool for introducing the pull mechanism to the factory in this project. Multifunctional teams and cellular manufacturing are important tools for creating cell-based production systems and U-lines that require expertise from several backgrounds. Therefore, they could be viable in improving the layout of the case factory. Finally, Ishikawa diagrams are utilised to assure that a defect in production is eliminated precisely through searching for the root cause of the problem and accordingly is a convenient tool for this project.

Table 2- Lean tools related to the project and their descriptions

Lean Tool	**Description**
Value Stream Mapping (VSM)	VSM is a visual lean tool for mapping the manufacturing plan of a product in order to highlight the current problems and develop systematical change (Hines *et al.*, 1997, 1999).
Just-in-time (JIT)	JIT is a lean tool that works by pulling production on customer demand whilst relying on other lean tools in order to reduce inventory levels (Karlsson & Ahlstrom, 1996).
5S	5S aims at organising the workplace in order to improve productivity while increasing safety levels (Hirano, 1995).
Kanban	Kanban is a visual manufacturing method where parts are supplied to the production line as needed, increasing efficiency and managing inventory (Sugimori *et al.*, 1977).
Multifunctional Teams	Multifunctional teams are a lean tool where people from different backgrounds combine their skills in order to achieve cell-based manufacturing (Sanchez and Parez, 2001).
Ishikawa Diagrams	Ishikawa diagram is a lean tool typically used to identify the root cause of a quality problem in production by dividing the problem in to different streams. (Ishikawa, 1968).

Cellular Manufacturing (U-line)	Cellular manufacturing is a method where the equipment and workplaces are organised in a small lot resembling a cell, often in a U-shaped production flow allowing fast reactions from employees (Liker, 2004).
Total Productive Maintenance (TPM)	TPM is lean tool that focuses on keeping all equipment in good condition to avoid interruptions and delays in manufacturing (Moore, 1997).
Standardized Work	Standardised work is a tool to get rid of Muri (overburden) by reducing every process to its simplest form, then applying best practices for manufacturing while considering the takt time (Liker, 2004)
Single-Minute Exchange of Dies (SMED)	SMED is rapidly changing the product to the next one in a process, usually under 10 minutes. This tool reduces lot sizes, therefore reduces inventory by improving Mura (Shingo & Dillon, 1989).
Poka-Yoke	Poka-yoke is a method for detecting defects. It corresponds to mistake proofing by the user or operator in a process in production with the aim of attaining zero defects (Shingo & Dillon, 1989).
Plan, Do, Check, Act (PDCA)	PDCA is a methodology also known as the Deming cycle for implementing control and constant development to processes and products (Tague, 2005).
Kaizen (Continuous Improvement)	Kaizen is an ideology that is based on creating a mechanism or culture that continuously accumulates improvements to the manufacturing processes in an organisation (Masaaki, 1986).
Jidoka (Autonomation)	Jidoka is a kind of partial automation, where employees working automated machines can identify a defect and find ways to correct mistakes immediately (Ohno, 1988).
Bottleneck Analysis	Bottlenecks are the processes that limit the capacity of the overall production. By improving bottlenecks total throughput can be increased. (Goldratt, 1984).
Andon (Visual Control)	Andon is a visual response method for shop floor production, where immediate attention is brought to problems as they occur. Employees are authorised to pause production when assistance is

	required (Liker, 2004).
KPIs	Key Performance Indicators is a tool that specifies goals that align with the operational or top-level strategy in order to develop concrete results that reflect success factors (Brooks, 2005).
SIPOC (Supplier, Input, Process, Output, Customer)	SIPOC or COPIS is a tool that puts all appropriate elements of one or more processes in a table for better understanding the overall relation aimed at making improvements (Pyzdek, 2003).
Heijunka (Production Smoothing)	A form of production that utilises smaller batch sizes to reduce unevenness (Mura) of work by mixing product variants inside the same process (Ohno, 1988).
5-Whys	5-Whys is a technique used in lean to find the root cause of a problem by repeating 'Why?' five times. (Ohno, 1988)
Takt Time	Takt time is defined as the speed of production associated with demand and is calculated as Available Production Time/Customer Demand. It provides a unit for the rate of production required to synchronise demand (Shingo & Dillon, 1989).

2.10.1 Value Stream Mapping

Value Stream Mapping (VSM) was initially developed in 1995 in order to map the current and the future state of a product or service from its initial state to delivery to the customer with reducing lean wastes from value streams (Hines *et al.*, 1997, 1999; McDonald *et al.*, 2002; Kalsaas, 2002). Value streams focus on the areas where an organisation adds value to a product, and a value chain represents all the activities in a firm linking the value streams (Taylor, 2005). Lean philosophy signifies that any activity within a company that doesn't add value must be eliminated. Therefore, the purpose of value stream mapping is to map the current and future states of the organisation as a visualisation tool in order to allocate wastes in the system and remove them (Rother & Shook, 1999). Rother and Shook (1999) depict VSM as mapping the current state of the work flow in order to redesign it focusing on reducing wastes, decreasing lead-times (Seth and Gupta, 2005; Chen and Meng, 2010; Tomar and Timari, 2016) and cycle times, reducing WIP, satisfying customer requirements and improving the material flow through layout. By doing so, a future state of the workplace is created which includes both materials and information on the same map (Emiliani and Stec, 2004).

Nevertheless, there were some general weaknesses to the VSM approach which affected the overall strength of the tool in lean manufacturing. Hines *et al.* (1997) also illustrated some key issues with VSM in the methodology the author displayed for implementation. These were: unobserved wastes such as energy and human wastes, the possibility of utilising other more useful tools, lack of understanding in taking results from VSM, most of the information being subjective (Singh and Sharma, 2009), not being linked with the corporate strategy, being time consuming, etc. However, more recent versions of VSM contain energy and human capacity factors in, and objective data is more consistently used in gathering information (Chen and Meng, 2010).

2.10.2 VSM Methodology

Figure 4 - VSM Methodology (Hines et al., 1997,1998; Tomar and Tiwari, 2016)

VSM methodology framework (see fig. 4) mainly takes five steps that are sequential. The first step in forming a VSM is (1) the selection of appropriate product family from the product mix in the organisation. (2) Then, data regarding the production and the demand for this product should be analysed, and the data regarding the current processes and operations should be utilised to create a current state VSM. This CVSM will depict the current situation of the organisation. (3) Once the CVSM is created and analysed, after brainstorming and revising the current map, a future VSM should be created using proposals and suggestions to eliminate waste and optimise processes and flow. (4) Subsequently, a plan for the implementation of this FVSM to the organisation must be created with the help of various lean tools. (5) Finally, after the implementation of FVSM, data must be gathered in order to compare and contrast with the planned FVSM results. This will demonstrate how effective the implementation plan was compared to the planned outcome and what other possible benefits it might have.

2.10.3 VSM Tools

Hines *et al.* (1988) identified 7 types of value stream mapping tools aimed to assist in improving the value streams. These are: (1) Process activity mapping; which is the initial step in mapping the process flows through re-engineering these processes with a holistic view considering the relations between them, (2) Supply chain response matrix; is a diagram that relates lead times with inventory which displays where the slow-moving stock exists (bottlenecks), (3) Production variety funnel; aimed at finding connections in other industries where solutions to current problems may exist, (4) Quality filter mapping; used to analyse the processes or functions regarding quality of the product, defect, and service in the supply chain, (5) Demand amplification mapping (also known as Forrester effect mapping); which analyses disturbances in demand in order to reduce cost and inventory amplification that can be caused by reordering, (6) Decision point analysis; establishes the variation points in push-pull demand in the supply chain, (7) Physical structure mapping; assisting in understanding what a particular supply chain looks like from the industry level in order to appreciate how the industry operates and express consideration to areas that may not receive attention.

2.10.4 VSM Symbols

VSM uses various symbols to visualise workspace and production. Figure 5 denotes the common VSM symbols that will be used at the results section of the dissertation.

Figure 5 - Common VSM Symbols (Tomar and Tiwari, 2009)

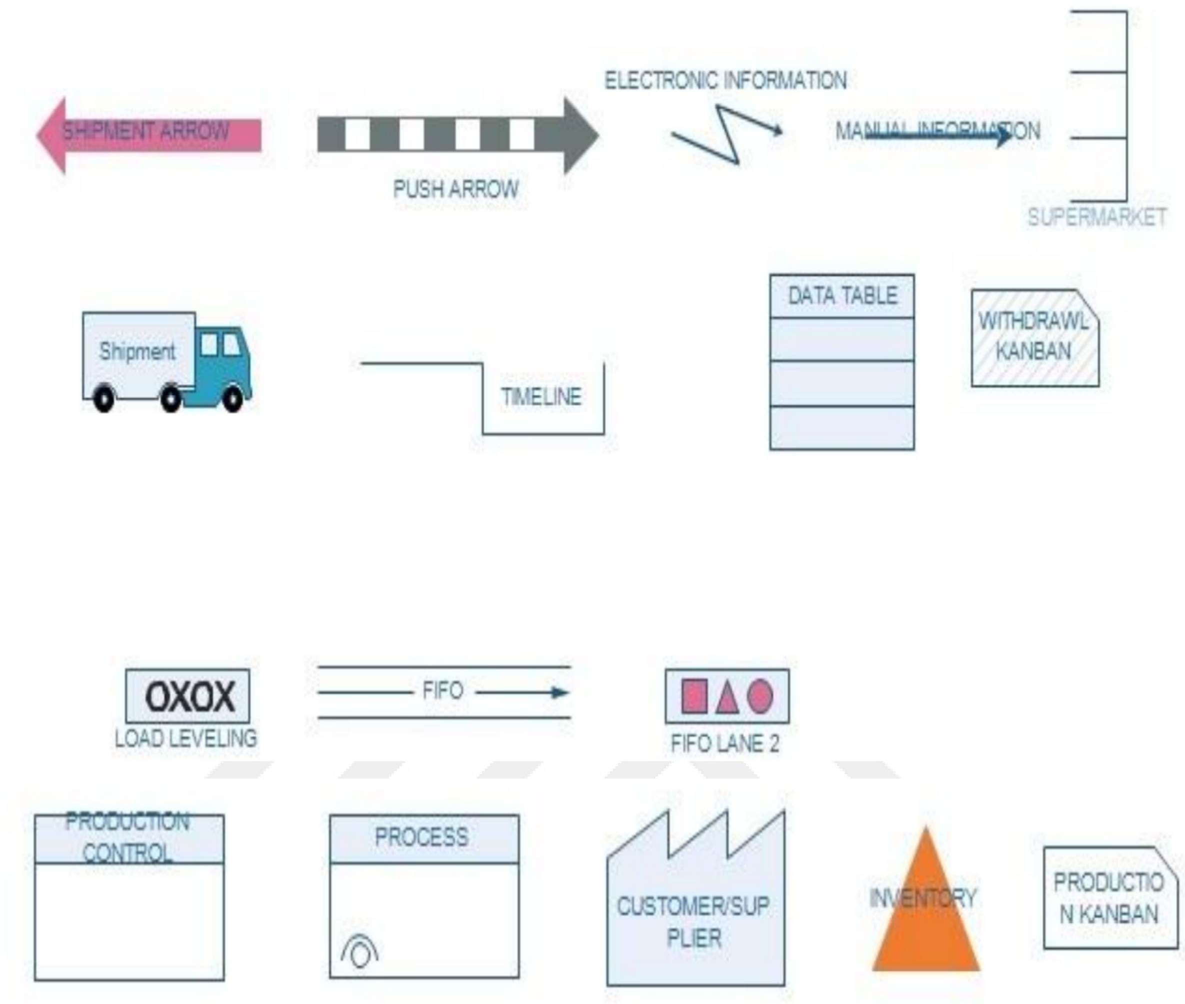

Figure 6 - Common VSM Symbols (Tomar and Tiwari, 2009)

2.11 Just-In-Time

Just-in-time (JIT) is a lean manufacturing tool that utilises minimum inventory throughout the organisation which emphasises the importance on utilisation of necessary products at the necessary time in the necessary quantity (Sugimori *et al.*, 1977; Karlsson & Ahlstrom, 1996; Spear and Bowen, 1999). Its primary concern is to reduce flow times in the organisation's manufacturing system interlinked with the reduced response times within the supply chain. Therefore, JIT serves as a pull system (Kanban) that pulls the products through the production line by demand. Ideally in this system, the objective is providing every process with one part at a time, and only when there is a need for that part. This is the underlining methodology of JIT. It is a plan to construct a supply chain that is synchronised, timely, and smooth (Yon, 1998). According to Yon (1998), small batch sizes, small buffer sizes and reduced lead times with minimal parts are the main characteristics of JIT. The reduction of lead times and lot sizes are the factors contributing to higher quality and customer satisfaction (Forza, 1996; White *et al.,* 1999; Katayama and Bennet, 1996). When a defected part is found in production, small lot sizes allow for the identification of the process that created the defect on the product. Thus, JIT can be seen as a control mechanism that emphasize or monitor the quality defects in a production line. On the other hand, the reduction in lead-times allow JIT to balance the changes in demand with a synchronised supply chain. It tolerates fluctuations in sales demand, since the reduced lead-times permit a reduced planning horizon for forecasting, and thus creating higher customer satisfaction.

Nevertheless, the main assumption of JIT is having a reliable and capable supply chain that works together as one, with appropriate communication and respect for each other. This proposes some issues especially to SMEs (small and medium enterprises) that are trying to implement JIT. Gupta *et al.* (2011) claims that SMEs might have difficulties applying JIT into their companies, and the biggest barrier is the lack of bargaining power with the external organisations.

2.12 5S Workplace Organisation

5S is a Japanese methodology for organising the workplace that consist of 5 Japanese words: *seiri, seiton, seiso, seiketsu,* and *shitsuke*. These words are translated to English as: 'Sort', 'Set in order', 'Shine', 'Standardise', and 'Sustain'. These topics also have specific goals that must be achieved by applying 5S which are: reducing the time spent on looking for an item, simplifying inspection, increase the volume of practical space, increase safety, creating a workflow that is smooth and simple, maintaining a workplace that is clean and pleasant to work in. Once these are applied to the workspace, standardising these goals and establishing procedures to guarantee the continuing of 5S is also essential. In order to fully implement 5S in an organisation, the firm must organise training sessions, and develop a work structure that is standardised and prepared for each employee. It is found that 5S implementation increased the safety levels, generated a clean workspace, improved productivity, and created a dynamic and beneficial environment (Gupta and Jain, 2013; Gapp *et al.*, 2008; Hirano, 1995; Osada, 1995).

2.13 Kanban System

Kanban system is a pull production technique, contrary to the traditional push production where parts produced from a station are delivered to the next station. In pull production, when the subsequent process is finished, the employees at the subsequent process go to the preceding process to demand the parts needed. Kanban is a form of card used in this system, and has two types; conveyance, and production (Sugimori *et al.*, 1977). The 'conveyance Kanban' is carried when going from a station to the preceding one. The 'production Kanban' is utilised by the subsequent process to order production of the part (Spear & Bowen, 1999). These both types of cards are carried out on the containers holding the parts. Thus, the flow of the parts delivered and the flow of the Kanban is opposite to each other. Therefore, the production actions of the final process are connected to the previous processes similar to a chain, which makes the JIT strategy possible. Nevertheless, Barker (1994) argues that transforming a traditional MRP based manufacturing system in to Kanban is rather slow but may be implemented for shop floor control when restructuring a complex system with poor initial design. However, MRP is still needed for planning supply contracts, capacity, etc.

2.14 Multifunctional Teams

One of the most outstanding features of lean production is the widespread utilisation of multifunctional teams. Compared to the traditional manufacturing organisations, the use of multifunctional teams in percentage is much higher in lean (Karlsson and Ahlstrom, 1996). These multifunctional teams involve of employees that have multiple job functions, and perform many different tasks. Therefore, these teams are usually located in the cell based positions in production. Rather than having specialised employees that work on a specific task only, multifunctional teams in lean consist of employees that can perform different tasks. This increases flexibility and reduces the dependence on a single employee. As a consequence, the number of job categorisation in the organisation decreases while personal employee functionality and skill increases (Karlsson and Ahlstrom, 1996; Cox and Blackstone, 1988; Sanchez and Parez, 2001; Shah and Ward, 2007). However, in order to create such teams, number of training tasks increase too. This training can be given in statistical process control, quality, maintenance, tools, computers, set-ups, and likewise. Additionally, the employees in multifunctional teams must also be trained to work in tasks that were performed by indirect departments such as handling materials, control, purchasing, and in-house transportation (Chen and Meng, 2010; Fullerton and Wempe, 2009).

2.15 Ishikawa Diagrams

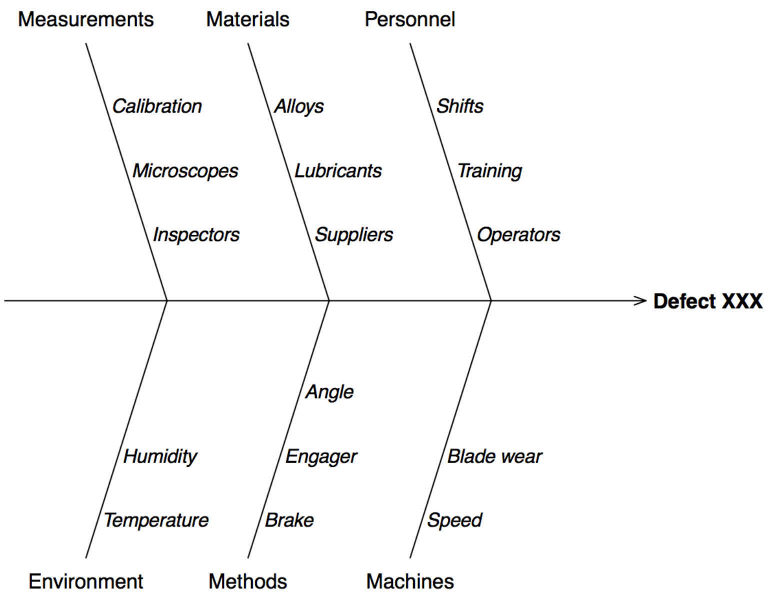

Figure 7 – Ishikawa Diagram example for manufacturing (by Daniel Penfield, Wikipedia)

Ishikawa diagrams, also known as fishbone or cause-and-effect diagrams, were created by Kaoru Ishikawa that are typically used to identify the root causes of a quality problem in production (Ishikawa, 1968; Meyer *et al.*, 1996). It is commonly utilised in product design phase so that possible errors and defects in the future can be prevented. It is a quality improvement tool that detects the source of an issue by dividing the effect in to different streams of causes and grouping them in categories. Organising the causes can reveal the elements that have the greatest impact on the end issue on the product. Since it is a good analysing tool that breaks-up a big problem into smaller parts, it is suitable for new design, understand or map current processes and feasibly emphasise opportunities. The Ishikawa diagram therefore allows the creator to understand how the elements of the process effect the outcome (Meyer *et al.*, 1996). In lean manufacturing, Ishikawa diagrams can function as a visual tool that can either be used as a quality control tool or be used to optimise a production line or a value stream. It can be developed to find non-value-adding activities in production and divide these activities into groups, which can then be arranged in order of significance.

Ishikawa diagrams used in lean manufacturing typically utilise the 5M model which distribute the cause of an effect as machine, method, material, man, environment(medium) (as seen in figure 6). Nowadays, information(measurement) is usually added as a 6^{th} bone yet, many different systems exist for naming the main bones. These main bones or subheadings can then be investigated for possible causes.

Since Ishikawa Diagrams involve shop floor interactions and involves training, it is not going to be used in this project.

2.16 Lean Implementation Framework

The successful implementation of lean manufacturing principles in any sort of industry is mostly related to how well the organisation initiated the plan (Sangwan, 2014; Sohal and Eggleston, 1994; Thanki and Thakkar, 2014). Therefore, it is crucial to create awareness of lean for employees in all hierarchical levels through the organisation (Sugimori, *et al.*, 1977; Sundar *et al.,* 2014). The aims of lean must be clearly explained especially to operational level workers and their supervisors, thus it is essential to provide internal and external training and education programs. Sangwan (2014) created a framework for implementing lean in an organisation that divides the process as pre-implementation, implementation and post-implementation that requires different inputs from managerial levels in order to create an effective environment for successful application (see fig. 7).

As seen in figure 7, lean implementation begins with the creation of a team that formulates and steers the whole process. This team should be able to spread the lean philosophy to both employees and the managerial levels and also educate and inform them about lean tools and techniques. This step is crucial for successful application of lean since, the managers who control operational level work must understand the reason why lean is being executed in order to fully engage and possibly assist in the implementation phase. This can also be a challenging stage because operational managers can perceive lean as being opposite or contradictory to the traditional methods used in production. This may lead to managers having a hard time comprehending the changes in production and therefore wanting to stay in their own traditional methods. In order to stop this from happening, it is essential to inform every significant employee about the reasons and aims of lean production and its tools.

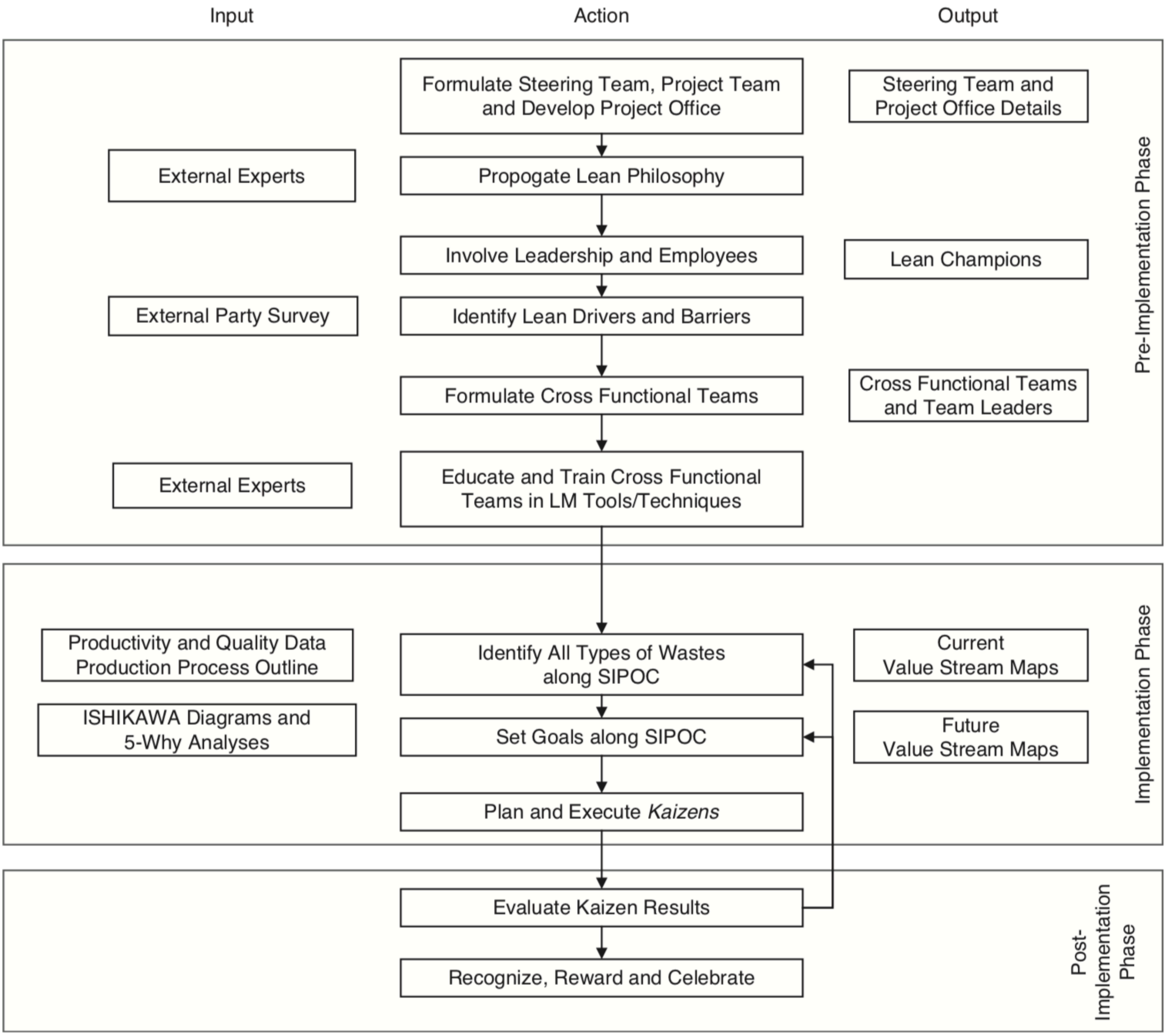

Figure 8 - Lean Implementation Methodology (Sangwan, 2014)

Subsequently in the implementation phase (as seen in fig. 7), a current state VSM is prepared for the existing production and the current wastes are identified on the VSM. For this dissertation SIPOC diagrams are not necessary since similar results can be depicted on the VSM without the use of a SIPOC. In this phase, all appropriate lean tools are applied like Ishikawa Diagrams, VSMs, Kaizen, 5S workplace organisation, Kanban, push-pull system, JIT, multi-functional teams, U-lines, cellular manufacturing, inventory management and so on. Afterwards, these lean tools are planned and executed through assistance of the future state VSM.

In the post-implementation phase, these recently stimulated production methods used for lean manufacturing should be evaluated and assessed in the ways they add value to the system (feedback loop seen in fig. 7). The positive results must be celebrated for creating a stable foundation, whereas negative results must be feed backed in to the VSM. Subsequently, an up-to-date VSM must be prepared in order to locate the most recent non-value-adding activities that may have ignited from the lean implementation and/or remained in the system. This positive-negative feedback therefore creates the dynamic of continuous improvement or kaizen.

2.17 Implementation Issues

Before implementing lean to an organisation, Womack and Jones (1996) discovered that customer focus is key to the lean philosophy which underlines the 'value defined from the customer's perspective'. If the value is defined incorrectly, the implementation plan is doomed to be impractical. Furthermore, Liker (2004) found out that one of the major pre-implementation issues are communication, either within the organisation or with the suppliers and customers. It is crucial to maintain the determination in this stage in order to gain maximum benefit in the long term. Subsequently, some issues that might develop during the implementation stage again lies with the effectiveness of the supply chain. On time delivery by suppliers allow the organisation to keep short response times to customers and allow for lower inventories (Hall, 1983; Womack and Jones, 1990,1996; Hines *et al.,* 2004). In order to truly improve performance and create a culture of quality, reduced inventories, cost reduction, and reduced lead times, lean must be implemented collectively through a supply chain and improvements must be made in suppliers, organisation and customers (Sanchez and Parez, 2001, Sangwan, 2014). Mohanty (2007) discovered that many organisations that implemented lean stated some initial improvements, however these were mainly limited, and failed to apply continuous improvements in the whole organisation. This can be a consequence of failing to create a post-implementation plan, which involves reviewing and analysing the results in the process. This procedure highlights where the achievements were accomplished and creates a path for continuous improvement leading to a profitable growth. Fullerton *et al.* (2003) discovered a positive correlation between organisations' profitability and the level of implementation in lean.

2.18 Applications in different industries

Mathaisel and Comm (2000) investigated the aerospace industry in US for lean initiatives and found out that there must be some 'best practice' methods that can be transcribed for each industry while trying to implement lean. Additionally, they suggest that implementing lean in a short period implies the change from complex to simple methods of production, whereas in the long run, companies have to invest money in lean plans in order to obtain the benefits of being lean. Bruce (2004) examined the textile industry for utilising lean and agile manufacturing techniques and concluded that the textile industry must be able to respond quickly and offer quick replacement, and therefore already utilises lean and agile manufacturing methods to keep up with short life-cycled products and reduced prices. Aitken *et al.* (2002) considered a company in the lighting industry and found out that the industry seemed very inapplicable with lean considering various supply channels; nevertheless, a combination of lean and agile tools aided the company to gain a competitive advantage. Howell (1999) and Pheng & Chuan (2001) studied the construction industry and discovered that applying JIT was extremely challenging because of the supply chain relationships of the industry, yet some lean tools to decrease on-site inventory was utilised.

2.19 Conclusion

Evidence in the literature about lean implementations and ways to reduce wastes in a marble processing factory is limited. This research's intentions are utilising various lean tools and implementation models, to create a promising lean application framework to the case marble factory. As stated in the previous chapters, the aim of this dissertation is; to diagnose the factory for each process, analyse the data on waste, develop lean methods to the factory where applicable, and make a proposal for the factory manager.

3 Research Methodology

3.1 Research Intentions

This research is organised to determine the application of lean manufacturing methods to a marble mining factory in Turkey, Antalya. The main objectives for this project can be simplified as:

- Diagnosis of the factory for each different process
- Analysis the data on waste
- Development of lean methods to the factory where applicable
- Proposal for the factory manager (implementation plan)

The first objective is constructed to analyse where lean manufacturing methods can be applicable in the processes that go on through the factory. The second and third objectives are intended to analyse the literature review on lean manufacturing methods and waste management with respect to the data gathered from the factory. The last objective is aimed to summarise all the findings of this research and deliver it as a proposal to the factory manager.

3.2 Philosophical Paradigm

There is a discussion in the literature for the perception of each individual philosophical paradigms for research. However, the most common paradigms are assumed to be positivism, constructivism and pragmatism. According to Crotty (1998), positivist observers are completely objective and see reality as a single truth, and thus it can be measured by reliable tools. Therefore, positivism is commonly seen as utilising quantitative methods in order to obtain data for experimental or survey research. Moreover, Levers (2013) argue that pure positivism is a weak paradigm in today's world since finding absolute truth is dependent on the tools and people's perspectives of the research. So, post-positivists believe that there is an absolute truth but it is almost impossible to discover. On the other hand, constructivism assumes that there is no single truth and it is created from the interpretations of the observers. Therefore, constructivists are more likely to utilise qualitative methods to examine reality from different perspectives. Finally, pragmatists believe that reality is constantly changing and thus the method that solves the problem should be used.

This research aims to utilise both post-positivist and constructivist approaches in order to assess the application of lean manufacturing methods to a marble mining factory. This is a consequence of having different approaches on lean manufacturing implementation methods on different companies. Additionally, there are no literature reviews on applications of lean principles to a marble mining factory. This results in evaluating different methods of implementation in several industries to form a basis for the marble factory. Then, additional to the data gathered from the factory, there will be in-depth interviews conducted with the managers of the factory to gain a more detailed and thorough understanding of the interior working environment. Thus, it can be said that this research will include a combination of methodologies. This research can also be identified as having a pragmatist methodology since there are both quantitative and qualitative data, and these are found in order to establish the ideal technique that should be implemented to the factory.

3.3 Methodological Design

In order to define the methodological design of this research, it is fundamental to understand what the research is intended for. This research aims to find appropriate applications of lean manufacturing methods that can be suitable for a specific company. In order to achieve this, there is a need for a literature review of the applicable lean principles plus the diagnosis of the specified company in order to locate the suitable processes that it can be applied to. Since the given nature of this research, it can be inferred that there is a two-step process to be followed. Therefore, this research has both the characteristics of a literature-based and a work-based project. As mentioned above, this project starts with a literature based design in order to find the theoretical aspects of lean manufacturing methods and subsequently gather data and information about the specified marble mining company which will involve a work-based research design. The methods used for the practical part of the project will include the researcher interviewing some key employees and gathering vital data about production. This is prepared to assess the factory in the further chapters.

3.4 Research Design

There are two essential research approaches that are recognised; deductive and inductive. The deductive research aims to obtain theories and suggestions on a specific argument from the literature and then test these ideas through experiments. The inductive approach on the other hand, aims at making an observation than drawing to a conclusion. In other words, deductive approaches to research aim at testing the theory where inductive approaches is involved with the creation of new theories (Gabriel, 2013).

This research is aimed at finding a suitable application for lean manufacturing methods for a mining company. Given the lack of information for such an application in the literature, this research's intention is to discover if these principles that are in the literature are applicable for the specified organisation. In this sense, this research can be identified as having a deductive approach since, it relies on the current theory on lean manufacturing and its implementation on a real-life organisation which is in a different industry than the traditional applications. This does not involve the generation of a new theory but the appropriate applications of a current theory on a new subject. Given the circumstances, it can be concluded that this research has a deductive approach to research design.

There are three main ways on investigating cases for a research. There is the single unit design, where the researcher focuses on a single case or population, and thus investigates that single case or population in an in-depth analysis. Then, there is the comparative design where the researcher focuses on the comparisons and contrasts of different companies or populations. This type of design is utilised for comparing an entity with relation to another. Finally, the third type of design is the multi-unit design, which is similar to the comparative design in the sense that it emphasises more than one unit. However, multi-unit design doesn't necessarily focus on the differences between the units but concentrates on generating a generalised knowledge about the case (Creswell, 2013). In this research, the single unit design approach is going to be held. This is due to the researcher's motivation with the given company. The specified marble company is the family business of the researcher of this dissertation and intends to contribute to the company in the near future. Therefore, the connection of the researcher of this dissertation to the given case company is the main reason this is a single-unit design. This may lead to believe that this is a participatory research however, this is a non-participatory research since there will not be an intervention to the company during the timeframe of the project yet a proposal for intervention will be submitted in the end.

This research aims to intervene with the case company on a basis of a cross-sectional design which is defining the question about data and interfering once where the data is needed. However, since the last objective of this research is to suggest a proposal to the company manager from the outcomes of this project, it can also be seen as a before and after design. Nonetheless, it should be clear that this research is not intended on intervening with the company. The theory from the literature will assist in defining an outcome for the organisation and focus on a proposal that clearly states the advantages or disadvantages of implementing lean manufacturing principles. This also states that this research has a retro-prospective design that involves collecting data from existing records and engaging to study the potential impacts of the new case which is lean manufacturing and subsequently compare with the traditional methods already used in the case company.

3.5 Data Collection Methods & Techniques

A literature review of lean manufacturing principles and the possible applications in different industries is already given in this dissertation. The data collection from the case company will therefore be related to the entities and subjects in the literature review. In order to gather data from the case company, interviews with the managers and some key employees are going to be set through the timeframe of this project. Interviews are utilised to gain data and information since former knowledge about the factory is limited, besides interviews with the employees of the organisation are undoubtedly an easier way to discover possible weaknesses and problems in the factory. Interviews can be structured, semi-structured and unstructured. Structured interviews are usually questionnaires that have closed-ended questions that have rigid answers like yes or no, or a selection from a list of choices. Utilising structured interviews limits the answers the interviewee can respond. Semi-structured interviews are similar to structured interviews however, it also investigates details. Also, it can be reorganised to fit the interviewee and possibly gain insight from an unanticipated thought. Finally, unstructured interviews are highly informal and include open-ended questions with no organised flow. These interviews generally give the respondents more freedom where patterns and developments can be identified during or after the research.

Bryman (2006) suggests that generally quantitative research involves structured interviews with questionnaires with a cross-sectional design whereas qualitative research involves a more unstructured interview design. However, when using these methods in conjunction, the possibility of unanticipated outcomes gets multiplied. Consequently, this research will use a combination of quantitative and qualitative methods and henceforth will have a semi-structured interview design. The researcher will gather the data and arrange the interviews by visiting the company in person. The researcher will also gather quantitative data himself from the factory if there is a lack of information in the associated subject. The semi-structured design will allow for a free-flowing discussion in order to get the most relevant data to the dissertation topic from the company. Nonetheless, given the nature of semi-structured interviews, as a consequence there will be a rich information pool (Creswell, 1998) where the researcher will then decide to investigate for further applicability. Creswell (1998) also argues that utilising mixed methods in research has some potential benefits such as having both a sense of rigour of the research and at the same time providing guidance to the reader what the researcher intends to find.

The factory does not hold any prior data regarding process times and lead times, wastes in production, bottlenecks, inventory turns. Some data was available concerning current inventory levels, delivery-on-time and production cost breakdown. These were gathered through one of the industrial engineers in the factory other than production cost breakdown data which was gathered through one of the accountants. Nevertheless, in order to gain deeper knowledge about the processes and the products in the factory and diagnose the current state of production, wastes and bottlenecks, interviews with factory managers (factory manager and the mining manager) and the CEO were necessary. Interviews with the factory manager and the CEO was prepared for understanding the current state of production, and the general issues they have regarding the factory. The interview with the mining manager was prepared in order to gain an understanding of the processes the stones and marbles go through until they are delivered to the factory. Interviews with the industrial engineer and accountants were arranged for collecting the data the organisation holds that concerns this dissertation. An interview with the sales manager was arranged for analysing the products, markets, and delivery times (see table 3 below).

Table 3 – Employees that will be interviewed

Job title	**Information to be collected**	**Abbrev-iations**
CEO	Strategic goals, general issues regarding production	**CEO**
Factory Manager	Processes in the factory, inventory problems, wastes, delivery times	**FM**
Mining Manager	Marble mining information, supplying the factory	**MM**
Sales Manager	Annual sales figures, demand and forecasts, products and markets	**SM**
Industrial Engineer	Bottlenecks, production layout, on-site inventory data, calculating machine processing times	**IM**
Accountants	Production cost breakdown, turnover	**ACC**

The employees seen in the table 3 will be interviewed, and the findings gathered from these interviews and any data collected will be attributed to each employee's abbreviation in the *Results* chapter of this dissertation.

3.6 Design of the Case Company Interviews

The aim of the interviews is to investigate the factory and each process for wastes. The first part consists of general questions in order to find the aims and current problems of the case company. The second part consists of questions related to wastes and how the problems are dealt with in the factory. These question types are included in order to identify current wastes and identify possible wastes that will have the most effect on the final lead-times. This data will be analysed further in the dissertation in order to eliminate these acknowledged wastes and set up for a proposal for the factory manager. The brief questions and their reason for inclusion are given in the table 4. The interviews will be of semi-structured kind however the main features will consist of the topics depicted.

On the other hand, the quantitative data on factual information will be accessed from the headquarter office of the company in Istanbul, Turkey. The themes of the quantitative data are given below. The quantitative data on performance will be gathered from the factory in Antalya, and these will include themes that are depicted below. If there is a lack of information in the given subject, the researcher will investigate and gather data on the issue personally.

Themes of quantitative data:

1. Factual Information
    a. Turnover
    b. Products
    c. Processes
    d. Employees
    e. Markets
    f. Production Cost Breakdown
2. Performance Information
    a. Levels of Inventory
    b. Process times
    c. Lead-times
    d. Delivery-on-time
    e. Inventory turns
    f. Quality Control

Table 4 – Qualitative Data Questions

	TOPICS	
1	**General Information**	
	Q1 What are the processes a marble goes through from mining to exiting the factory?	This question was included to discover each and every process in the factory in order to locate the bottlenecks and construct an ideal layout for the factory.
	Q2 Currently, what are the biggest challenges facing the company/factory?	This question was included in order to determine the current challenges according to the factory managers from their perspective. Possible waste data can be collected accordingly.
	Q3 What are the short-term/long-term goals for this factory?	This question was set in order to understand the current and future desired state of the factory to be able to align the objectives with the company.
2	**Information on waste**	
	Q4 What are the current wastes in a single process that effect the delivery on time that you know of?	This question was set to be able to identify possible wastes that are already identified by the managers and are in consideration.
	Q5 From your perspective what are the processes that are found to be useless and effect the delivery on time the most?	Again, this question is set similar to the Q5 yet this question is included in order to find the process that can have the most effect overall if lead times are shortened.
	Q6 What are the things that frustrate you the most and how do you deal with a problem?	This question was included to understand the attitude of managers towards the operators in the factory when a waste is discovered. Some sub categories of this question can consist of how a defect is dealt with, how do you know the work is done correctly and so on.

3.7 Reliability and Validity

Reliability and validity are concerned with the quality of the data gathered in terms of accuracy and effectivity. For this research, reliability will be achieved by triangulation of data through interviews from different managers in the company. This will introduce a reliability barrier since the company manager, mining operations manager, the chief executive and a couple of sales and inventory managers will be interviewed. The data gathered will be reliable since interviews will be held with a high number of candidates in the same company. The validity of the data is also protected since the data is relevant to the research topic. Although the interviews are semi-structured, the research topic necessitates a diagnosis of the factory in order to find and locate the possible processes that lean manufacturing can be applicable to. Therefore, the validity is preserved in this research by both the relevance to the research topic and the relevance of the staff that is been interviewed.

3.8 Ethical Approval

This research consists of gathering primary data from the case company, and thus requires an ethical approval from the university. The ethical approval confirmation and the related proposed consent form and the PIL (Participation Information Leaflet) are attached in the Appendices section of this dissertation (Appendix 1, 2, 3). Every interviewee was made aware of the nature of this project and they were provided with a PIL and a consent form. Due to ethical approval restrictions for gathering primary data, the names of the interviewees and the name of the company are not visible in any part of this dissertation.

4 Results and Analysis

4.1 General Information about the company

The case company is one of the well-known companies in the marble industry in Turkey. The current 2018 forecast for turnover is around $18-20 million. However, in the last few years, the organisation went through an investment period which forecasts an increase in the turnover each year (see table 5). Their main product is named *Lymra Limestone* which branches in to other different types of stones according to their texture and colour. The overall colour of the marble is white which is important in the marble industry since white and grey colours have stable sales demands where different colours can have unusual demands throughout the year. There are 42 countries that the company is delivering to and these can be broken down into several markets. The sales department is divided into specific markets that the company operates in, these are: North and South America, Europe, Australia, Middle East, Asia (info gathered from SM).

Year	Turnover
2016	$9.5 million
2017	$10.5 million
2018	$18-20 million
2019	$25-30 million

Table 5 - The turnover of the case company in the recent years (including forecasts for 2019)

Figure 9 - The factory located next to the quarry

The company is segmented into branches that have different functions, but mainly it can be seen as being divided in to three sections. The first and the second sections are in Antalya where the marble quarry and the factory exists, and the third one is in Istanbul where the head office and sales department resides. Currently (early 2018), the organisation has 240 employees including all three divisions (info gathered from ACC). The organisation has become an international exporting company specialising in the natural stones sector, in blocks, slabs, and tiles. It owns site registrations in 19 marble quarries, however the biggest one of these 19 quarries and the factory are located in Antalya. The main product is limestone and the average capacity of this quarry is around 12,000 – 15,000 tons of limestone each month. The company also plans to start production in 2 more sites that have different products like *Elmali Beige, Mersin Grey,* and *Gaziantep White (*info gathered from CEO).

The factory is located right next to the quarry (see fig. 8) so that there is no time and energy loss between extracting the stones and producing plates. This way, the production starts almost immediately after the stones are extracted. The extraction of the stone is done separately from the factory and thus there are two different managers for stone extraction and factory production. Therefore, this way the extraction division acts as a very trustworthy and dependable supplier to the factory. The marble mining division works faster than the rate of production and so has a surplus of blocks which is sold to customers that buy blocks (info gathered from CEO). The overall detailed production cost breakdown of the whole organisation can be seen in table 6 and figure 9 below (information gathered from ACC).

Table 6 - The detailed production cost breakdown for 2017

Detailed Production Cost Breakdown (2017)	
Description	**Total**
Direct Labour	$ 2.142.562,73
Electrical Costs	$ 307.368,28
Factory Food Costs	$ 113.814,27
Vehicle Maintenance Costs	$ 5.996,09
Purchased parts (for machines and other equipment)	$ 280.985,97
Packaging Costs	$ 1.035.424,15
Forklift lease Cost	$ 31.379,30
Insurance Costs	$ 97.768,44
Machinery Maintenance and Depreciation	$ 737.299,12
Logistics Costs	$ 431.925,43
Customs Loading Costs	$ 443.329,01
TOTAL	$ 5.627.852,80

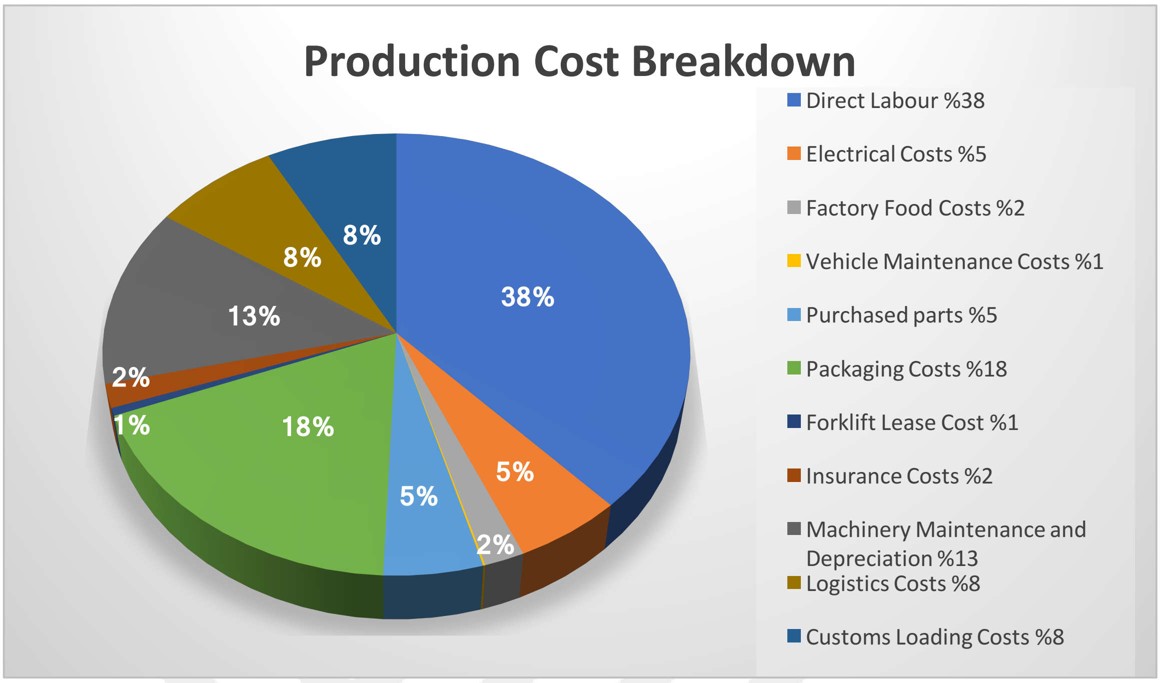

Figure 10 - Production cost breakdown pie chart (2017)

4.2 From Mountain to Marble Plates

Extracting marble and placing it to a building or a house is an extremely long process. There are numerous processes that go through from extracting of a 20 tons of marble block to installing as decoration in a house. These processes that the case company delivers will be explained briefly in this section. However, in order to understand why some processes are done in that order, firstly one has to understand how the business works and the geological factors that limit production. The quarry in Antalya consists only on limestone, however there are levels of the mountain that differentiate the limestone quality. There are currently 12 benches (levels) that differ from 6 to 9 meters in height, and these benches are made wide enough so that earthmoving vehicles such as excavators and loaders can work. The fossils or imperfections in texture of the stones increase with height. Therefore, going from the bottom to top the stones are: *Perla* (completely white), followed by the best-seller *Myra,* then *Santa* (white with small granules), and finally on the top *Fiorito* (covered with fossils). Although the best-selling stone is in the middle region of the quarry, extracting the stones can't be done if the upper levels aren't extracted (see fig. 10) (information gathered from MM).

Figure 11 – The benches of the quarry

4.2.1 Mining

The initial stage of marble extraction is locating and observing the stone underneath. This requires the skills of geologists and mining engineers to interpret the quality of the stone and whether or not it is applicable for dimensional cutting and other processes. Some stones may have historic cracks or may not be feasible to extract. Boring machines that take samples from earth assist in determining if the stone below is applicable for manufacturing or not. Once this process is done and the stones are found to be suitable, then the actual mining process begins. Nonetheless, this can take several months to clear up dirt and other loads in the way to get to the good stone that is suitable for production (info gathered from MM).

4.2.2 Extraction

After mining is complete, the extraction can begin. The extraction starts with drilling vertically through one of the benches. This is done via specific drilling equipment which have tolerances and limits, which limit the size of the extracted block. However, this is not a great setback since they have to be able to fit other equipment such as loaders, containers, lifting cranes and so on. The drill is done both vertically and horizontally to the bench of stone in order to cut it in to a big cube of stone. Then, metal wires are used in circular motion to remove the stone cube from the mountain. This process continues until the required length is reached. Once this process is done, the stone is cut in a cube but is still sitting on the mountain. So, the next step is to push the big block of stone to the bench that is located beneath the block. However, in order to be able to pick the block up from the ground, some debris and dirt has to be located where the block will fall. Subsequently, excavators slowly push the marble block and once the block falls to the other bench it can now be picked up by loaders.

The block of marble doesn't usually survive the fall since there are natural small cracks in the stone that break in the event. This results in to smaller pieces of marble that are created by the fall. These pieces are then taken to an empty area where they can be cut to the biggest rectangular dimensions possible via circular wire cutters. The pieces that are in good shape become the blocks and other irregular looking big pieces become rubbles. The extraction division then takes these blocks and rubbles to a stock are located near the mountain. The blocks can be sold to customers or they can be delivered to the factory, however the rubbles are not sold and are directly delivered to the factory (info gathered from MM).

4.2.3 Entrance to the factory

Figure 12 - The rubble cutting machine (on the left) and the block cutting machine (on the right)

The factory has two main entrances; one for rubbles, and one for the blocks. Each block and rubble gets delivered to these entrances with loaders that put the stone on a stationary crane and from there on travels on mobile carriages. The blocks directly go in a machine (Katrak) that cuts the block into thickness adjusted plates simultaneously (see fig. 11). Additionally, the blades that cut the stone have diamonds attached to their surface, and these blades have to be measured and maintained in order to resist wearing off. This process takes a long time both on cycling time and change-over time. This is due to the block being very heavy and sensitive when being cut which involves further time-consuming steps to hold the divided plates together such as handling, fastening, calibrating, lowering. The process takes about 7-9 hours depending on the length of the block. Nonetheless, this machine provides a clear cut with thickness adjustable blades which makes certain other processes unnecessary. On the other hand, rubbles need to get measured to figure out where the cuts should be made and makes one thick cut at a time (see fig. 11). However, after this process, both block plates and rubble plates go through the same processes (not including the horizontal cutting) however on different production lines since they can differ in thickness and area. After this initial process, both big rubbles and blocks are now made in to plates that can vary between 2 - 7 cm in thickness according to the order. These plates then go in to the production lines which consist several consecutive processes such as cutting, calibrating, filling, etc. Rubble plates go in a production line that is smaller in width whereas the block plates go in a production line parallel to the rubble plates with the only difference of larger width (info gathered from FM). These processes will be explained in the current state Value Stream Map (see fig. 13 & 14). The layout can assist in visualising and getting a better sense of the processes going through the factory (see fig. 12).

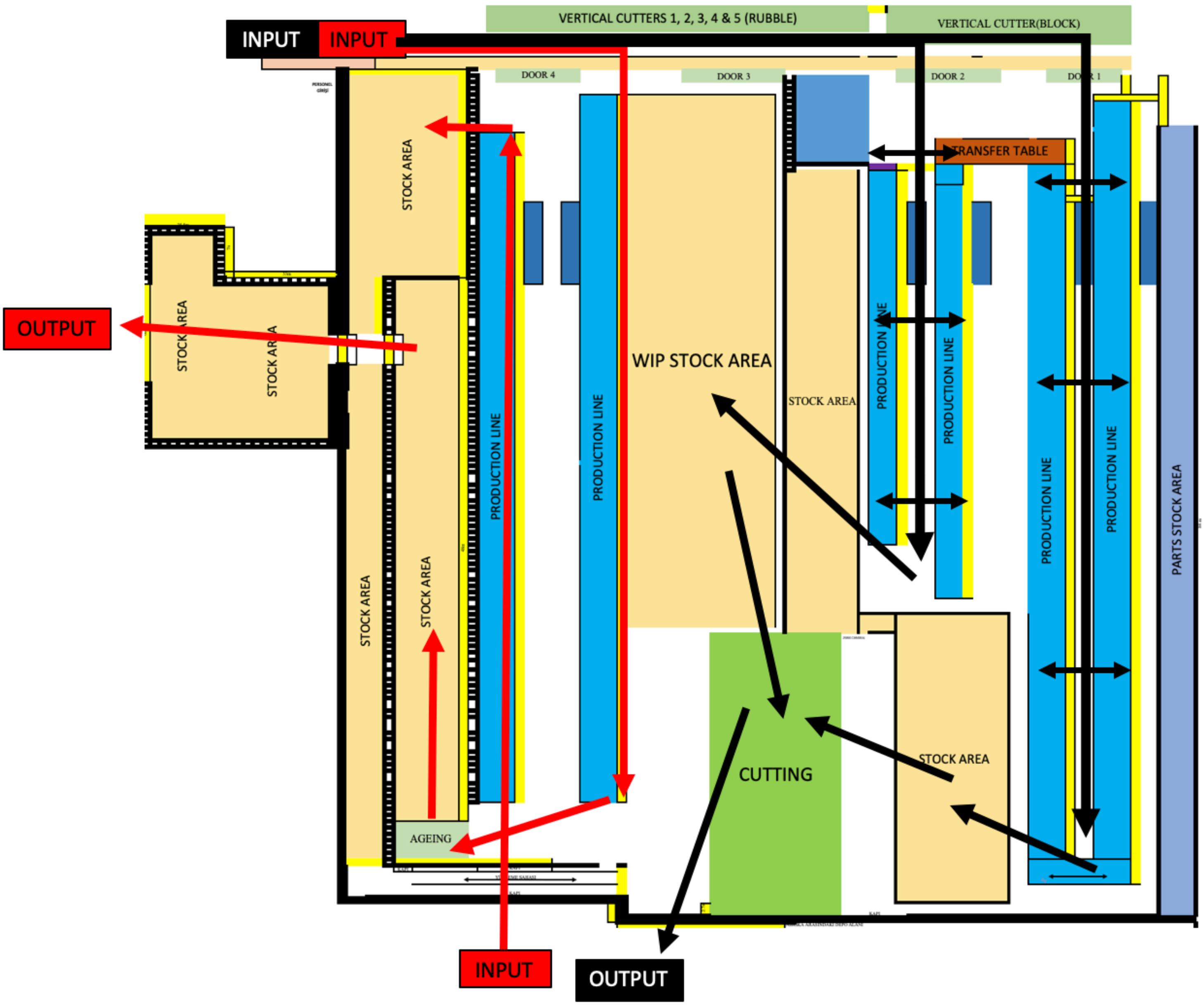

Figure 13 - The factory layout indicating the flow of production

(red arrows = rubbles, black arrows = blocks)

In figure 12, the layout of the factory and the production flow are depicted (info modified from IE). As mentioned before, the factory has two main entrances; one is for blocks, and the other for rubbles. On the top of the layout, the vertical cutting machines can be seen, which are the first processes in the production. From there on they both (rubbles and blocks) have production lines that go through the factory and specified stock areas for each style. Only one of these production flows is opposite to the others (leftmost red arrow, see fig. 12), and that is because of the restrictions in the space between two productions lines and the fact that the machinery can be utilised from one face only. Also, the input for that particular line is coming from the broken tiles stock area which is outside the factory. Other than that particular line, the inputs and outputs of the factory exist in each opposite side. It can be observed that the combined stock area holds approximately the half of the whole factory (stock area in left part for rubbles, stock area in the centre for blocks). However, this is mainly due to the volume and the surface area of these plates. These plates that have large surface areas are placed in the centre of the factory either to dry up, or wait until order has been placed.

4.2.4 Factory Processes

In order to get a better understanding of the processes in the production line, Value Stream Mapping (VSM), which is a lean manufacturing tool, is utilised to perform a current state map (see fig 13 & 14). Both of these VSMs are excluding the extraction of marbles and only depicting the processes in the factory. The marble extraction division can be seen as a supplier to the factory. Similarly, the logistic tools are also done by the organisation, meaning the firm owns the transportation vehicles both coming in and out of the factory. The database icon depicts where the stock is recorded to computers. In this VSM, the production control can be seen as the factory managers that work according to the sales departments criteria. The organisation doesn't own or utilise a MRP or ERP system. The production control is done via excel sheets that are created by the sales department depending on the customer orders. The factory works in three 8-hour shifts, meaning it is never shut down except one day of the week. Therefore, the weekly capacity is determined as six 24-hour days. The excel sheet that consists of the customer orders are then analysed and broke down into days which creates the weekly schedule (based on info gathered from FM).

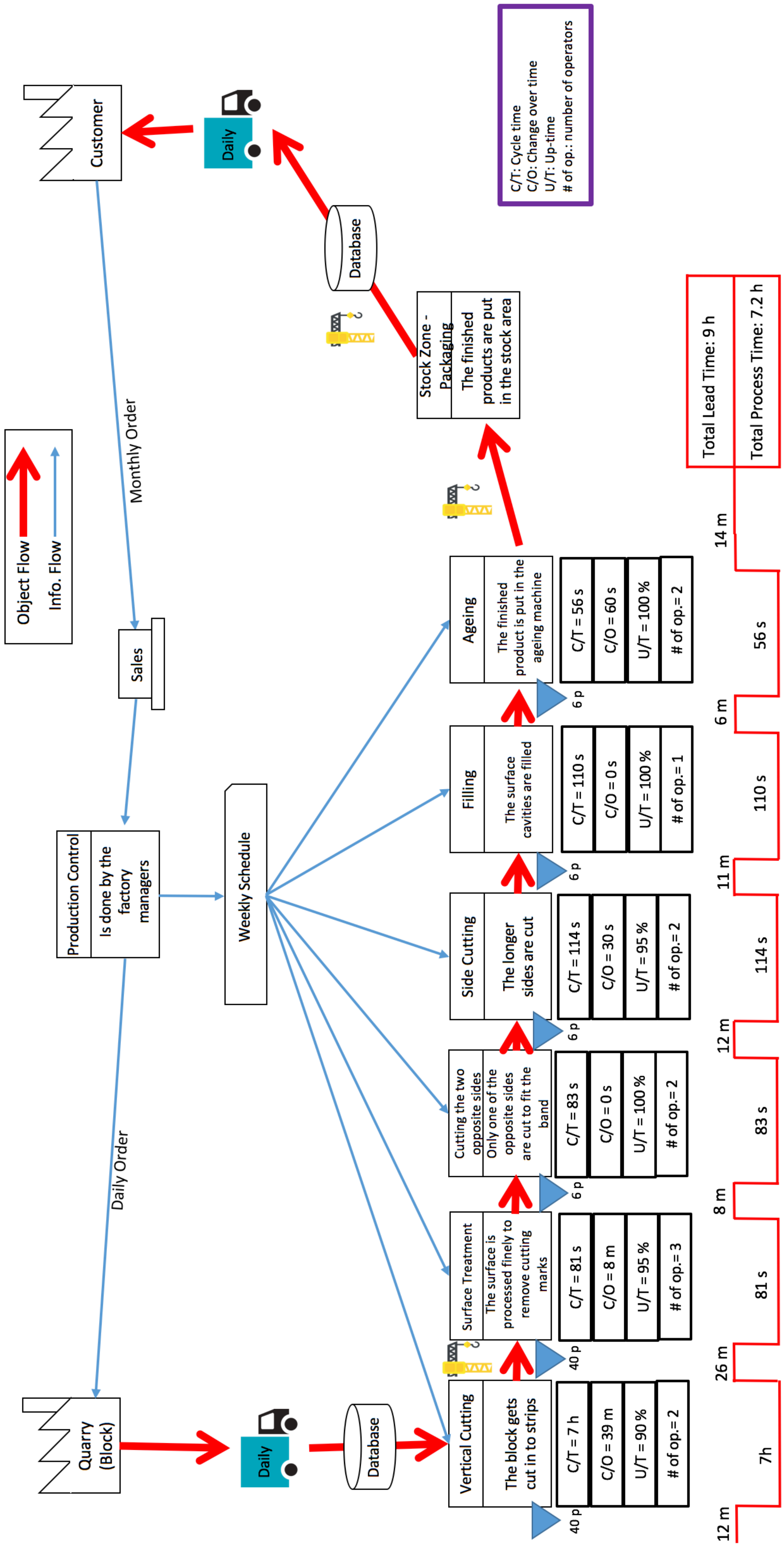

Figure 14 - The current state Value Stream Map for Block production prepared according to the information gathered from the IE

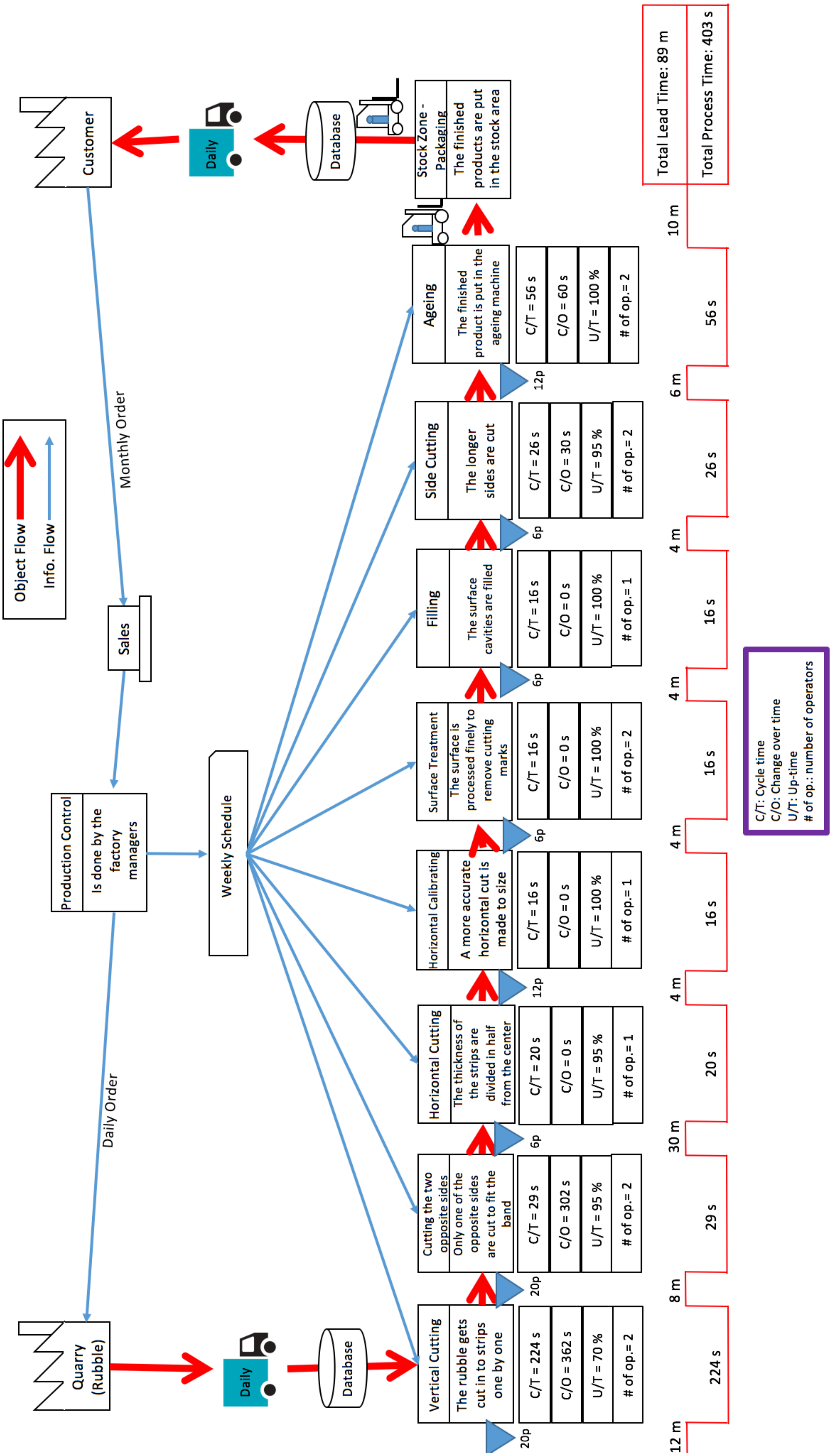

Figure 15 - The current state Value Stream Map for Rubble production prepared according to the information gathered from the IE

The processes inside the factory are similar for rubble and block plates, so for the sake of simplicity, understanding one production line is enough to comprehend the other. Hence, the rubble production line will be explained (info gathered from FM). After the initial vertical cutting machine cuts the big rubble in to plates, these plates are then fed to the production line one by one. At this stage, the plates' thickness is more than double of the desired thickness, and its sides have irregular shapes. Therefore, the first process is cutting the two opposite sides of the plates in order to make it fit to the production line. Then, a horizontal cut from the centre of the plate is made in order to reduce the thickness. As a consequence, two plates are now formed from a single larger plate. This process doubles the output which generates more input for the subsequent process. In the VSM, this is the reason why the inventory doubles after this process. Then, each plate that was cut in half proceed into the calibrating machine, where the plates are cut from their surface in order to more accurately adjust the thickness. This machine is basically calibrating the possible errors from the preceding machine. However, this process is done with face brushing blades which leave marks on the surface. Therefore, the plates proceed to the surface treatment machine where they are processed finely in order to create a well-honed texture on the surface. Some customers order plates that are just honed, so depending on the order, the plates may continue on the line or pulled

Figure 16 - The production lines

Figure 17 - The filling machine

out after this process. However, the stones naturally have small dents or cavities in them, which brings us to the subsequent process. The honed plates progress to the filling machine where these natural occurring dents are filled with a limestone powder mix (see fig. 16). Next, these plates are cut from the sides that have irregularities, which is done by operators. In this process, the operators inspect the plates and eliminate plates that are cracked or not suitable to sell. The plates that went through the filling machine have to sit for 3 days in order to fully dry up. Depending on the customer order, others can move on to the ageing machine. The ageing process is done in a chamber full of small stones and it vibrates in order to give the stone a worn off look (see fig. 17). This is the last process in the factory, and after this process the plates are taken to the stock area where they are packaged in wooden creates ready to be shipped.

Figure 18 - The Aging machine

The block plates go through the same exact processes described above with small differences. These plates are larger in area and thus heavier, which makes them harder to move. Thus, when moving these large plates around the factory, the crane inside the factory or suction equipment is utilised. Another difference is the lack of the horizontal cutting machine. This is due to the first machine (see fig. 11) being able to make thickness adjustable cuts.

4.3 Delivery times

The organisation works in a 'make to order' fashion, and therefore the delivery times are higher than other industries. One reason for making the production 'make to order' is because the stones go through different processes and so they have different finishes. In fact, there are 9 types of finishes for each type of stone. Therefore, one can imagine if there was finished goods stock for each one of these types the inventory would become much bigger (9 x 4=36 different finishes possible). Additionally, some stones can be unavailable in a specific time, which can be a result of debris laying on the stone in the quarry, or the preceding stone has to be cut first to reach the desired one, etc. Below are some of the customers and their delivery times over a 3-month period (see table 7) (info gathered from SM). The delivery times are calculated from the date of the order until the date of physical shipment of goods. It can be perceived that the delivery times are variable and can change considerably between 15 – 55 days. The customers are also a factor since they are from different countries such as Italy, United States, China, Turkey, Qatar, United Arab Emirates, Germany. There are also some exclusive customers that demand quick reaction such as *A&P, Taj Italia, Resin Co.* These are vital customers because they provide the company with bigger projects and exclusive offers. For example; *A&P* is a customer that also contributes in marketing the product *Anatolian Fiorito* in US which thereby increases the demand; *Taj Italia* is a company in Dubai that only works in big construction projects which is beneficial for marketing and sales. Specific orders can be another variable since the finish and the dimensions of the marble tile can significantly change the lead time of production (info gathered from SM).

Table 7 - The delivery times for some of the customers (2018)

Order Date	Delivery Date	Delivery time	Type	Finish	Customer
9.11.2017	3.01.2018	55 DAYS	MYRA	HONED	Tile Emporio
20.11.2017	3.01.2018	44 DAYS	FIORITO	BRUSHED	Mazista Cape
27.11.2017	4.01.2018	38 DAYS	FIORITO	BRUSHED	Rain Marble
5.11.2017	7.01.2018	63 DAYS	FIORITO	AGED	Royal Stone
18.12.2017	10.01.2018	23 DAYS	FIORITO	POLISHED	Derya
29.12.2017	14.01.2018	16 DAYS	MYRA	RAW	Dragoss
6.12.2017	18.01.2018	43 DAYS	AF	BRUSHED	A&P
27.11.2017	21.01.2018	55 DAYS	MYRA	HONED	Antalya Building
21.12.2017	22.01.2018	32 DAYS	FIORITO	AGED	Pyramids
4.01.2018	25.01.2018	21 DAYS	MYRA	HONED	Floors & Walls
30.12.2017	30.01.2018	31 DAYS	MYRA	HONED	Stone World
16.02.2018	28.02.2018	12 DAYS	MYRA	POLISHED	Vinsiya
14.02.2018	28.02.2018	14 DAYS	MYRA	HONED	Marble Homes
13.02.2018	1.03.2018	16 DAYS	AF	BRUSHED	A&P
19.02.2018	1.03.2018	10 DAYS	MYRA	HONED	Resin Co.
15.09.2017	8.03.2018	174 DAYS	FIORITO	POLISHED	USA Tile
9.02.2018	8.03.2018	27 DAYS	MYRA	POLISHED	Taj Italia
1.03.2018	15.03.2018	14 DAYS	FIORITO	AGED	Stone TTI
19.02.2018	18.03.2018	27 DAYS	MYRA	HONED	Hard Stone
19.02.2018	29.03.2018	38 DAYS	MYRA	HONED	Haussmann
26.02.2018	3.04.2018	36 DAYS	MYRA	HONED	Dalmatians

4.4 Inventory

In the marble business, inventory is a big problem since the product is immovable, heavy, and large and yet it is sensitive to fractures. It also has to wait 3 days if the plates went through the filling machine. There are also quality differences between stones which makes a surplus of lower quality plates that aren't sold because there is no demand for it in the market. Given the nature of mining marbles, the quality is a variable that can fluctuate in size, appearance and durability. Therefore, this requires large amounts of inventory to be trapped in the factory, and it is a very slow and energy consuming process to move these around. The factory has no sense of prioritization between different products, since when a stone goes through the processes, it is then placed to anywhere in the factory where there is an empty space. Just walking around the factory is even difficult because of the large amount of stock laying around (see fig. 18). So, in order to overcome this chaos of stock, a categorisation of products in an arranged manner is crucial.

Figure 19 - The inventory inside the factory

The most recent data of inventory shows that the factory is holding around 237,000 m^2 of marble combined (info gathered from IE). This figure can be perceived as being gigantic if the last year's sales figures are taken into account (see table 8). However, the CEO of the company claims that the 2018 forecast is around 21,000 m^2 each month which sums up to 252,000 m^2 demand for the year. This gives us a stock cover (inventory/ daily demand) around 293 days. This figure depicts that there is 293 days' worth of inventory stuck in the factory, however it should be mentioned that the inventory doesn't depict the finished goods since some of the inventory is of lower quality and doesn't have a market for itself yet. In terms of value, the inventory has an average of $ 20 (fluctuating between $8 - $40) per square meter, which makes the total inventory worth $ 4.7 million if the sales prices are used in the calculation. On the other hand, in order to observe the value being processed, the factory cost per day equals $ 18,000 where an average of 1450 m^2 of material is processed daily. If the value of stock is calculated from this cost, then it is worth $ 2.9 million. Either way, it can be concluded that inventory has a very high value because of necessary overproduction of plates and some quality fluctuations.

Table 8 - The sales figures for the 4 main products (2017)

AF			
THICKNESS	FINISH	M²	TOTAL SALES %
2 CM	BRUSHED	95,45	0,23%
3 CM	BRUSHED	102,36	0,25%
4 CM	BRUSHED	146,54	0,35%
	TOTAL:	344,35	0,83%

SANTA			
THICKNESS	FINISH	M²	TOTAL SALES %
2 CM	POLISHED	17320,02	41,53%
3 CM	POLISHED	199,18	0,48%
	TOTAL:	17519,2	42,00%

MYRA			
THICKNESS	FINISH	M²	TOTAL SALES %
2 CM	POLISHED	8356,02	20,03%
3 CM	POLISHED	6337,86	15,20%
5 CM	POLISHED	86,56	0,21%
2 CM	HONED	2773,56	6,65%
3 CM	HONED	71,22	0,17%
2,5 CM	RAW	2037,46	4,88%
5 CM	RAW	1330,39	3,19%
2 CM	SWEEPED	36,6	0,09%
	TOTAL:	21029,67	50,42%

PB			
THICKNESS	FINISH	M²	TOTAL SALES %
2 CM	POLISHED	1126,38	2,70%
3 CM	POLISHED	153,84	0,37%
2 CM	HONED	440	1,05%
3 CM	HONED	103,24	0,25%
2 CM	BRUSHED	157,71	0,38%
3 CM	HAMMERED	784,72	1,88%
	TOTAL:	2765,89	6,63%

Additionally, it is necessary to observe the sales demand in order to understand the inventory line up in the factory. To be able to categorise and organise the inventory, it is essential to give priority to some products that sell more. In this case, it can be seen that *Myra* and *Santa* are the two main products that cumulatively make up 92% of the total sales (see table 8) (info gathered from SM). Therefore, the inventory line-up must give priority to these two products.

5 Discussion

5.1 VSM – Future State

In order to create a future state VSM for the factory, first the wastes should be identified. Thus, it is necessary to define value from the customer's perspective so that waste can be identified and eliminated. In this case, the value can be seen as the final form of a marble plate or tile, where the plate has no defects or quality problems such as surface cracks, corner fractures, and it has the correct size and dimensions with the demanded precise finishing. With this depiction of value, almost all of the processes in the factory are essential and are value-adding activities since they perform accurate cuts to ensure size and dimensions, surface processes that confirm the quality of the end product, and finishing processes that certify the demanded product. There are also some type 1 Muda activities such as inspections, in-factory transportation of stones, and packaging. However, the essential waste in the factory can be seen behind the processes where the products remain until they are shipped – inventory. The inventory of both finished goods and WIP (work in progress) is one the biggest wastes and they are mainly created by overproduction, poor scheduling, producing earlier than the customer requires. (Taiichi Ohno, 1988; Womack and Jones, 1996). Although overproduction is one of the major wastes, in the marble industry it is somewhat essential. This is due to the nature of extracting marble from the mountain where the quality of the marble is layered in benches that can be extracted only if the preceding stone is extracted. This means that even though the sales demands are fluctuating between products, the supply of different stones are stable. Although this makes supply forecasting easier, it creates a geological bottleneck for the factory if the mountain is seen as a supplier.

5.1.1 Kanban

Additionally, the lack of a MRP or ERP system in production control may be a factor in creating high values of inventory. In order to stabilise and control the production more effectively, a Kanban system may be useful to assist in managing the stock of both work in progress and finished goods. Introducing a Kanban system may have benefits such as; controlling the production more effectively and efficiently, being able to observe where the congestions in production are, assisting in managing the inventory (Sugimori *et al.*, 1977; Spear and Bowen, 1999). If Kanban is introduced to this system, the processes would be a chain of events that are tied with each other and every product can be monitored by simply looking at the Kanban chart without the need for an additional production control (see fig. 19). This chart helps in simplifying the production control, and gives live information about products.

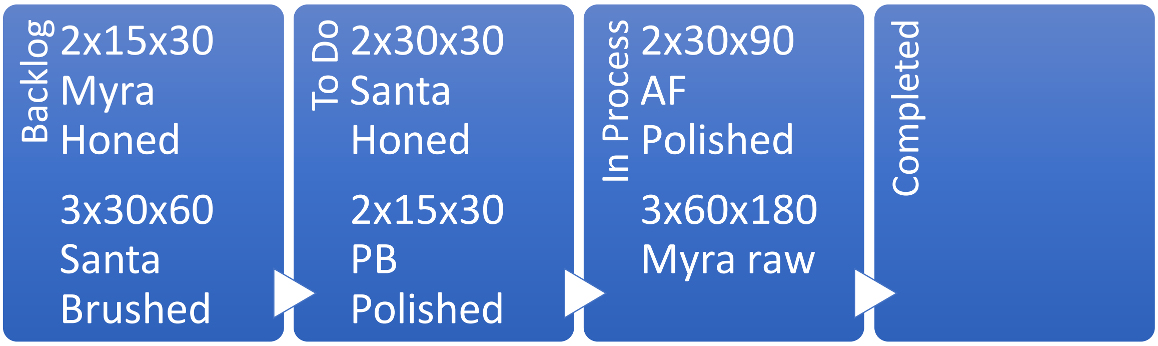

Figure 20 - A depiction of a possible Kanban chart for production control

With the inclusion of Kanban cards in production, WIP can decrease substantially. In this case, there is a 3 day WIP because the stone has to dry up after the filling process. If Kanban cards are introduced to the production, then the WIP can decrease significantly since there will be only enough dried plates for packaging or ageing or further cutting processes with the Kanban cards. Kanban will be used mostly in the shop floor production, where the need or the supply of parts or items are more vital. Common parts or items that are necessary for production are the synthetic abrasives that polish or hone the stone surface, the disc cutters and their diamond wire segments, the filling chemicals, epoxy or other chemicals related to the order, machine oils. Other than these items, the supply of chipped tiles inventory to the production line can be carried out with Kanban too. This scheduling of supplying chipped tiles back to production with the use of Kanban can be a positive factor in slowly diminishing the work-in-progress inventory or the defected parts inventory.

5.1.2 Multifunctional teams

The use of multifunctional teams is also a very significant tool of lean manufacturing. In the factory, the skill of each employee can translate in to m^2 since higher the skill, higher the output from the raw material will be. The organisation already has a database where the employees put in the numbers they produce in m^2, which can then be translated to how effective that employee is regarding to all of the other employees. However, these can differ in the shop floor activities that are done individually. With the introduction of multifunctional teams, the factory can increase the efficiency of an employee by initiating training programs for these shop floor personnel to work in cell based positions. This would imply that these personnel should be trained in activities other than their original work description. Therefore, creating this kind of multifunctioning teams would assist in creating highly effective and efficient employees which would reduce the necessity of an individual worker (Karlsson and Ahlstrom, 1996; Cox and Blackstone, 1988; Shah and Ward, 2007). It can also assist in making the production leaner and more agile by lowering the down-time of each process and thus increasing both machine and personnel utilisation. In order to make this a reality, U-lines or cellular manufacturing stations can be used in production, enabling smaller multifunctional teams to deal with more processes while using less manpower.

5.1.3 Work Cells

With the inclusion of the Kanban system, both work cells and the stone supply would need forecasts in order to manage the capacity and plan staffing and inventory. In order to visualise these changes, a future state value stream map (FVSM) is depicted (see figure 19 and 20). The real benefit of these alterations would be reducing the lot sizes which means reducing WIP inventory. If the operations that are linked with each other are arranged as cells that have multifunctional teams and smaller lot sizes, inventory will reduce, there will be less unnecessary movement of products and people while capacity utilisation is heightened. In the FVSM, since the side cutting, horizontal cutting, calibrating, surface treatment and filling processes are in the same production line and are linked with each other via conveyors; these can be seen as a work cell even though they have to be in a line so that conveyors can connect the plates between these processes. The preceding process, which is the initial vertical cutting can be seen as a work cell on its own, since it involves other processes such as; moving the stone with a crane, calibrating the cutting machine, cutting, and moving each single plate. This reformation of work cells also assists in achieving a clearer flow from the layout (see fig. 22). It can be observed that the layout with the inclusion of work cells have a specific material flow for each type of production.

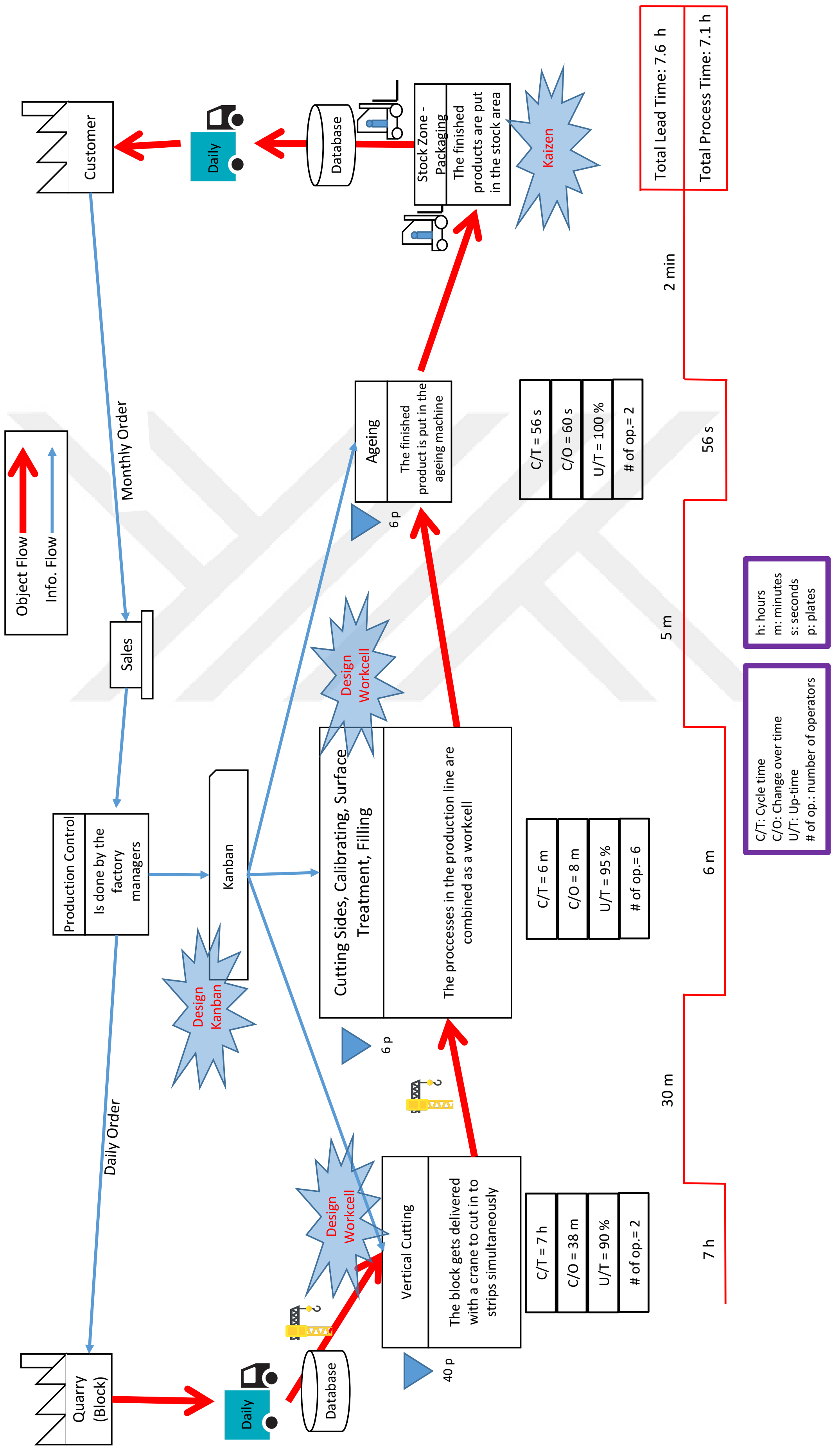

Figure 21 - The future state VSM for the block production

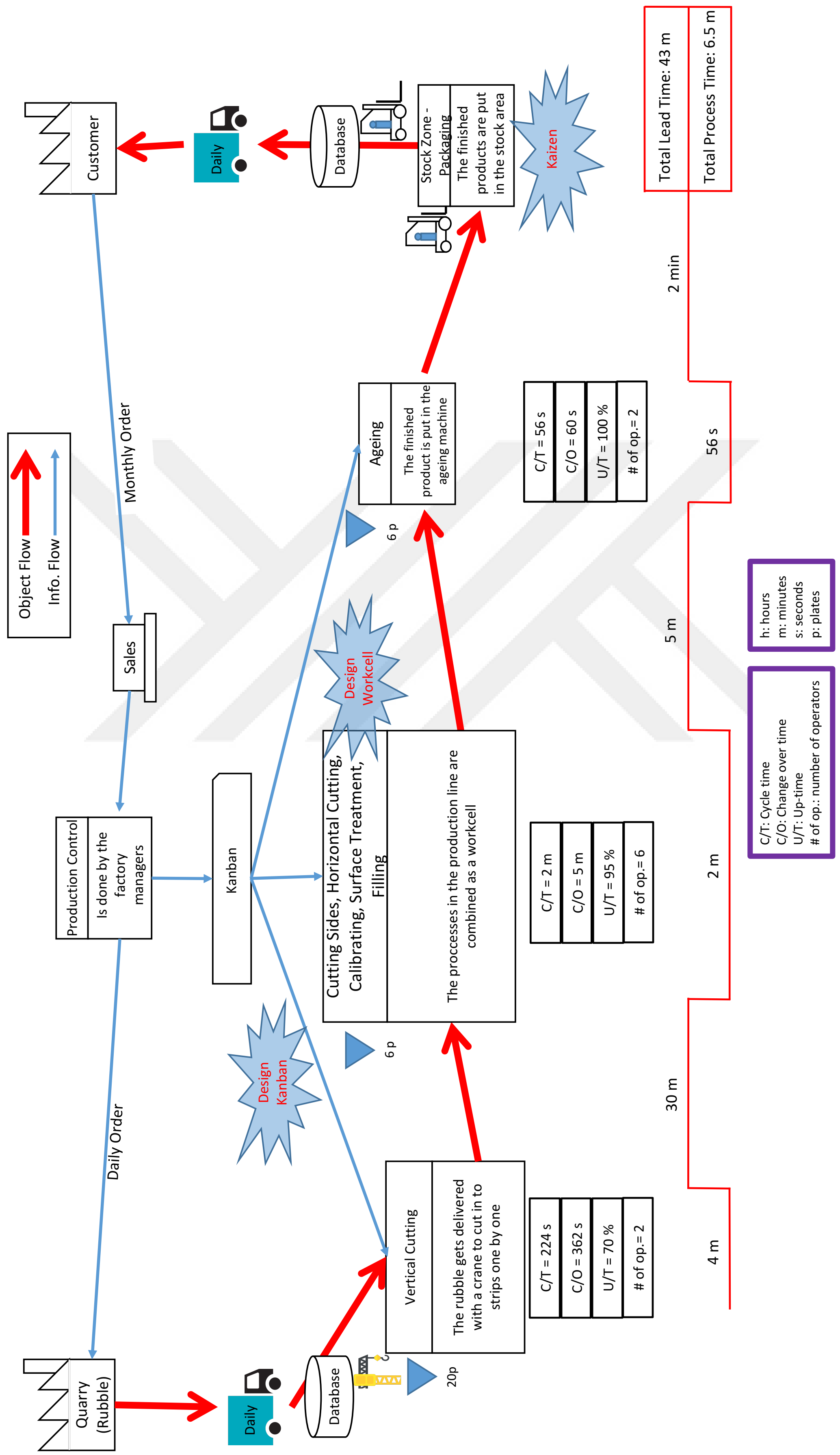

Figure 22 - The future state VSM for the rubble production

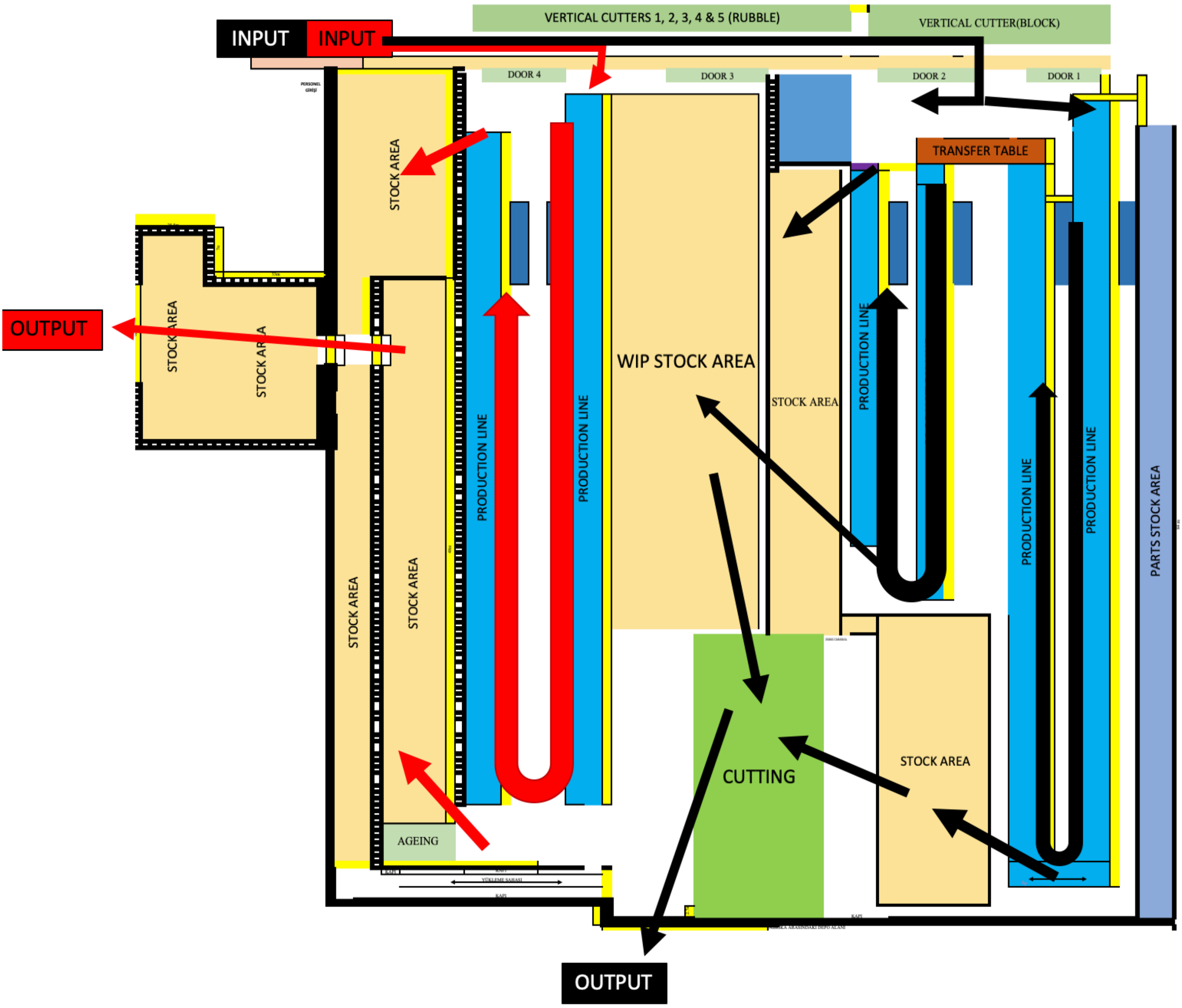

Figure 23 - The factory layout with the work cells included

The new layout shows working cells for each production line inside the factory. The production line for rubbles were already shaped like a U-line production, but the future state involves all the production line to be shaped in a U-line. This will allow for multi-functional teams to operate in a higher efficiency level compared with the last layout diagram. Also, the stock areas are organised, so the transition between production and delivery is made smoother. Additionally, the cutting processes outside the entrance are also made in to cells, since these processes involve multiple interconnected procedures. It can be observed that the future state layout has more product flow and is straightforward.

5.2 Inventory

Given the nature of the marble industry, there are no possible ways to minimise inventory to the lowest possible unit. This is a consequence of the stone having internal fractures during extraction or even when it was formed naturally. Thus, when a stone is being processed through the factory, it can be cracked anywhere on the plate (sides, corners, centre) which makes it untradeable in the dimension it was produced. However, skilled employees cut these fractured plates to a lower dimension from a line that will maximise the output. Yet, this creates inventory that isn't necessary at the time of production. From a lean manufacturing point of view, this can be seen as a waste (Womack and Jones, 1996; Taiichi Ohno, 1988), however it is essential in the marble industry. To overcome this unwanted inventory while saving up as much stone as possible, a configuration of the inventory according to each dimension and stone type is crucial. From the experiences in the factory, it can be concluded that it is a necessity to categorise the finished goods in order to reduce delivery time and control inventory. A lean tool such as the 5S workplace organisation can be utilised to create a more efficient and less time-consuming plan. This 5S implementation would not just

Figure 24 - The new classification of the stock area in frames (left), the old stock area (right)

categorise and shape the disorganised stock, but aid in improving service, safety, and efficiency of the inventory utilisation. In order to categorise the stock, the results from the inventory analysis section can be utilised to give prioritisation to the more important products (in this case Myra and Santa are dominating the sales figures). Combining the current inventory line-up with this categorisation, a stock area model is depicted in figure 24.

This model creates a stock area that is labelled according to thickness, stone type, and finish. Additionally, these different products will be organised in columns, making it easier to transport or deliver from there (see fig. 23). This reduces the redundant transportation work, and speeds up the delivery process of inventory, while opening up new spaces for newly produced products. It can be assumed that it is also much safer to move products this way, because it eliminates the need for continuous movement of goods which decreases the risk of fractures during movement and restricts the possibility of human contact. This way the 5S stock area will not only increase the product's safety, but also the employee safety through the factory.

It can be observed that the old stock area (depicted in figure 23), is just plates that are placed side by side, without any order or classification. The new stock area consists of frames that are separated from each other sufficiently that they don't collide with each other. They also have wooden beams that act as pads in order to protect the plates' sides from cracking. Additionally, there can be wooden beams between each plate or group of plates in order to act as padding between plates to increase their safety (can be put in the metal frame's cavities – see fig. 23). It also enables simpler and quicker locating and moving of plates. This also opens up an additional space in the factory. In a sense, the categorisation enables more inventory to be occupied in less area.

Subsequently, the implementation of these metal frames as classification starts with transporting the current inventory in the stock area on the metal frames. This should be done according to the classification chart presented in figure 24. The different types of products are distributed according to their sales forecasts that are made from the 2017 sales statistics. It was perceived that 90% of the sales were made from the two types of stones: *Myra* and *Santa*. This is the main reason these two products are occupying most of the stock area. However, the stock area plan is not a direct representation of the sales figures, since other products such as *Anatolian Fiorito* and *Perla Bianca* also has to be extracted from the mountain and processed before other stones can be produced. This results in a slight exaggeration of the stock area for these products (10% in sales transcribed to 20% area in stock planning). Therefore, the stock area is actually arranged as a combination of last year's demand and the current inventory line-up.

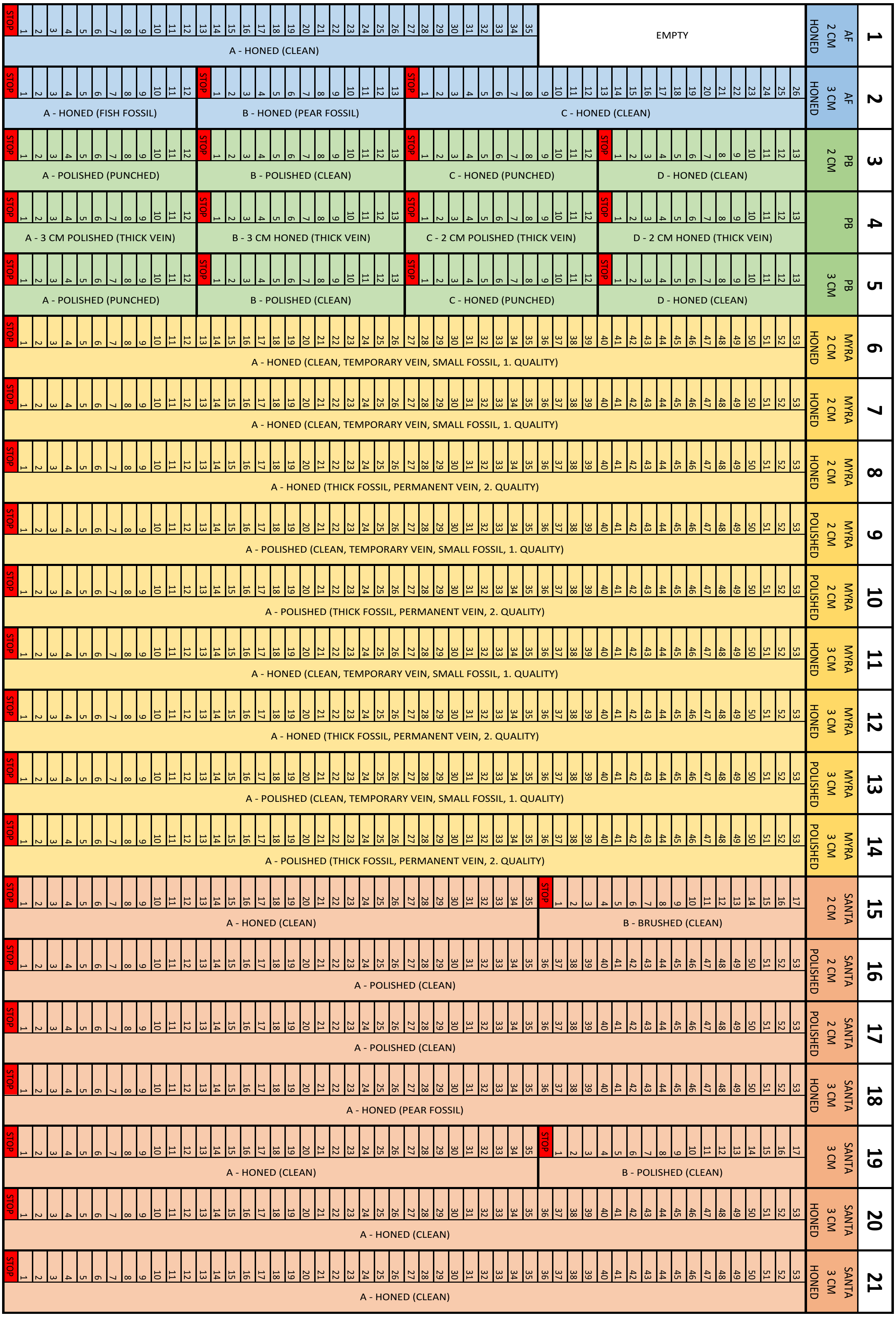

Figure 25 - The new classification of the stock area

5.3 Variety in Products

Another reason the inventory levels are high is the vast variety of these products. Each product can differ immensely in thickness, side length, area, finish, and stone type. Although there are only 5 variables that effect the product, the amount of variety currently in the packaged finished goods inventory is 304 types (see Appendix 4). These 304 types include both large and small plates, although it can be observed that large plates made from blocks have less variety and thus can be managed with the stock area classification depicted in figure 24. The higher variety mainly originates from the smaller plates that are made in the rubble production line.

The number of variables increase the output exponentially, which creates untradeable goods that have to wait in stock until some customer gives that specific order for that product. In order to lower the inventory levels, these variations in products must be reduced. The organisation could benefit from introducing some sort of standardisation to their products. However, some customers might be choosing to work with the case company because of the specific dimensions they can produce. If this is the case, the organisation might choose to have two different types of production, such as standardised products and specialised products. This would involve two types of production; the standardised production has only one or two thickness and area dimensions available, where the specialised production has any variable possible that are in the tolerances of the machinery. Relative pricing can be utilised since the cost of producing a standard product will be lower, where the cost of a specialised product will be higher. This also enables the inventory to be more practical and manageable. Standardised products could stay in the finished goods inventory, so that when an order comes it can be directly shipped from the warehouse. Whereas specialised products would continue working in a 'make to order' fashion. Therefore, this would have benefits to reduce the delivery times, since the finished goods stock could be utilised to make quicker shipments for standardised products. Given that the organisation currently only works with specialised products, the delivery times for these wouldn't be effected. This is also a valid long-term goal to reduce the variety in the inventory since standardised products will start to dominate the inventory.

5.4 Is lean implementation appropriate?

One of the most vital characteristics of lean manufacturing is holding minimal inventory throughout the factory. However, in the marble industry, even holding minimal inventory through the processes is very hard since the minimal unit is a block of stone. Additionally, even if minimal inventory is achieved through the processes, finished goods inventory is still going to be an issue, since the small fractures that happen naturally in the stone can change the dimensions of the plate resulting in unnecessary but inevitable inventory. Nonetheless, this does not mean that inventory can't be reduced or controlled. Other lean tools such as VSM, Kanban, Kaizen, 5S workplace organisation, and using multifunctional teams can be very beneficial to the case company. The utilisation of such tools can assist the case company in identifying non-value adding activities and having a lean framework could aid in eliminating these wastes. Kanban can be utilised as a valuable production control mechanism since the current production control is done by factory management via Excel files. Introducing multifunctional teams could increase employee efficiency, reduce the defects, and reduce lead times.

5.5 Costs and Benefits

Overall, the FVSM (see fig. 20 and 21) depicts that with the implementation plan applied to the factory processes, the total lead time is reduced from 89 minutes to 43 minutes for rubble production, and 9 hours to 7.6 hours for block production. This reduction in lead times are a consequence of executing 5S workplace organisation, Kanban, and multifunctional work cells. With the adoption of multifunctional teams, the number of operators in one shift of a product family reduces from 13 to 8 which is a 38% reduction of direct labour. This reduction is gained from the decrease of idle times of employees in multifunctional teams. If the 2017 figures are used to calculate the direct costs, overall 38% reduction of labour translates to $815,000. Naturally, these figures would change, but it can be observed that lean manufacturing implementation would overall add value to factory by increasing the skills of employees, organising and controlling production and inventory, help identify and eliminate wastes, decrease lead times and delivery times, and decrease costs in the long run.

5.6 Implementation Plan

According to Sangwan (2014), the implementation of lean manufacturing consists of three phases which are: pre- implementation, implementation, and post- implementation. Pre-implementation phase involves identifying lean barriers, involving leadership and employees, creating cross-functional teams, and training in lean philosophy. Accordingly, the case company should begin the implementation process by creating the multifunctional teams and start training them across departments. Factory managers and operational supervisors must be trained in lean philosophy so that they understand why they are going through this change. It's essential to create an awareness and explain the aims of lean manufacturing for employees from all operational levels (Sugimori *et al.*, 1977; Sohal and Eggleston, 1994; Sundar *et al.*, 2014).

Subsequently, during the implementation phase, all other wastes should be identified through the production and establish specific goals to achieve completely value adding processes. In this phase, current and future value stream maps must be utilised to indicate what the company is aiming to form. Since there is no MRP or ERP system for production control, a Kanban system can be established. This will involve making a Kanban chart for the factory managers so that they can locate each product in the production. Utilising Kanban as a production control mechanism may eliminate the need for another control method which can reduce current non-value adding activities related to production control. Kanban system could also have implications in reducing both WIP and finished goods inventory, since it introduces a pull mechanism resulting in smoothing the work distribution which prevents overproduction. Given that Kanban works better in smaller batch sizes, the next step can involve reducing the lot sizes for the production line. Smaller batch sizes are also significant characteristics of lean manufacturing and JIT systems (Yon, 1998; Karlsson and Ahlstrom, 1996; Sugimori *et al.*, 1977). However, with the nature of the marble industry, batch sizes can't be reduced less than a particular unit of stone (rubble or block). Since the supplier of these stones are the mining division of the organisation, controlling the supply would be easier. Another vital characteristic of JIT is also minimal unit inventory through the organisation. Nonetheless, in the marble industry it is somewhat essential to hold inventory both at the input end and the output end. This is where JIT restricts the implementation in the marble industry. Yet, the inventory is still one of the major wastes in the factory. Therefore, an organisation of the inventory and the 3 day WIP stock area can be a suitable place to start.

5S workplace organisation methods should be planned and executed. In this case, inventory organisation should be the place to start, since inventory is one of the current biggest problems in the factory. The stock area reorganisation depicted in figure 24 should be utilised to rearrange the stock area so that the capacity and accessibility increases, and at the same time space utilisation increases. A possible future implementation could be introducing electronic labelling methods such as RFID tags or barcode labelling to the packaged goods inventory. Once the stock area is organised, a 5S implementation can be introduced to the work cells. The work cells for initial cutting and the production line could be analysed for non-value adding activities, and subsequently initiate an implementation plan to eliminate these wastes. After the lean implementation phase, the results should be matched to the previous data and should be evaluated regarding the current and future state value stream maps. This data should then be a base for identifying other non-value adding activities in the process and must create a feedback loop for continuous improvement.

6 Conclusion

Although lean manufacturing was created in the automotive industry, the methods related to lean are known to be applicable for other industries and shown numerous benefits all around the world. The marble industry is very unrelated to the automotive industry, and the major differences are the minimal amount of inventory needed to continue production, number of parts, processes, products, and many more. Nevertheless, this does not denote that lean manufacturing or lean thinking is not relevant in the marble industry. This research depicts the possible outcomes of implementing lean manufacturing methods and ways to reduce wastes in a marble processing factory in Antalya, Turkey. All of the processes that go through the marble factory was examined and analysed to identify wastes in production.

According to this paper, the case marble factory has some issues such as holding large amounts of inventory, having a disorganised and unsystematic stock area, and having too much variety in products. Given the nature of the marble industry, reducing inventory to a minimal state, which is the main goal of lean manufacturing and JIT, was not optimal for production. However, it was found that with the utilisation of lean manufacturing tools such as multi-functional teams, work cells, 5S workplace organisation, Kaizen, Kanban, and VSM, the case company can gain benefits in cost reductions, increasing delivery-on-time, reducing lead-times, and reducing wastes and defects in production. Therefore, even though the authenticity of lean manufacturing gets altered by the application in the marble industry, the lean manufacturing tools are advantageous and beneficial to the case company. An implementation plan is given in this dissertation for the factory managers if they are intending on applying these methods to the factory.

Given the lack of information in literature on lean applications in the marble industry, it is necessary to gain more knowledge in this area before applying lean to every marble processing company. However, the general ideas behind lean thinking such as identifying value, identifying wastes, re-organisation, and continuous improvement can be very effective tools in diagnosing and re-evaluating processes in a marble factory. As the research has demonstrated, lean manufacturing tools can be indeed applied in a marble factory in order to identify and eliminate wastes in production.

6.1 Limitations

This research was conducted within a master's degree program in University of Warwick, and thus had a time restriction of approximately 9 months. It also had a time restriction on the period where the researcher can gather data which was done in Turkey within 4 weeks. These limitations may have affected the work prepared in this dissertation in terms of depth. Additionally, the lack of information in literature of the lean applications in the marble industry may have restricted this research, and further investigation might be beneficial in order to generalise the information given in this dissertation.

6.2 Contribution

This dissertation serves two main purposes for the researcher. The contribution to the case company is relevant to the researcher of this paper, because the company is owned by his family and the researcher aims to continue working in this direction in the future. Therefore, the analysis of the factory processes, and possible lean implementations are influences to the company by the researcher. Furthermore, this research contributes to both the case organisation and the researcher himself.

Additionally, this research fills a gap in literature since there are a lack of information on lean implementations in the marble industry. Thus, this research can be a base to other potential studies related to the marble industry and lean manufacturing.

6.3 Future work

This research analyses the processes and the progress of the case marble factory, and depicts the possible outcomes from a lean manufacturing application. The future of this project will involve a proposal to the factory managers by the researcher, and according to the manager's response, the implementation plan suggested in the discussion section of this research will be conducted. As depicted in the implementation plan, after this implementation of re-organising the stock area, providing Kanban and VSM for production control and reducing lead-times, and creating work cells by utilising multi-functional teams; a data collection to inspect the new design will be taking place.

Several other lean manufacturing tools like Poke-yoke, Autonomation, TPM, PDCA, SMED, KPIs, that were not utilised by this research could be sampled or attempted if lean is found suitable. If the foreseen benefits of lean implementation are found to be proceeding in the production, then another future-state VSM should be prepared and further identification of wastes should take place. This would be accomplished to resume with the path of lean manufacturing methods. Continuous improvement is essential for maintaining a lean operation. On the other hand, if the results of investigation seem to be insufficient or unsatisfactory, lean implementation will either need a reconstruction from the given data or it will possibly be dismissed.

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Appendices

Appendix 1 – the ethical approval confirmation e-mail from WMG course office

wmgcourseoffice@warwick.ac.uk

Wed 13/06, 16:36
Tuzcu, Utku;
Grinsted, Susan
Inbox
You forwarded this message on 13/06/2018 16:39

Dear Mr. Tuzcu,
Warwick University ID Number: 1793428

Thank you for submitting your Supervisor's Delegated Approval form to the FT Course Office for the project: Application of Lean Manufacturing Methods to a Marble Factory.

Your reference number is REGO-2017-WMG-0649.

You now have the appropriate approval in place to begin your study.

Please ensure you insert a copy of this email into the appendices of your project.

Best Wishes

Laura Dobson
WMG Full-Time MSc Course Office
wmgcourseoffice@warwick.ac.uk
go.warwick.ac.uk/wmgftmsc
+44(0)24 7657 4206

Appendix 2 – Consent Form

This sheet seeks to provide information, and advice, with respect to an individual's participation in support of the specified research project:

1. *The project is entitled 'Application of Lean Manufacturing methods to a Marble Factory ', and will consider the implementation of lean principles related to this subject;*
2. This research is being conducted by *Enver Utku Tuzcu* in support of his studies for an MSc at the University of Warwick, and this research is self-funded by the student;
3. The research is being supervised by *Dr. Susan Grinsted*, *s.grinsted@warwick.ac.uk,* who is an external supervisor appointed by the University;
4. Participation in this research is totally voluntary, and assurances are given to the effect that no negative consequences will arise from refusal to participate, from limiting participation, or from withdrawing (prior to dissertation submission) input that arose from any earlier participation in the research project;
5. Each individual is advised to fully consider, with others if necessary and prior to participation, any disadvantages, side effects, risks and/or discomforts that may arise from participation in this research;
6. Unless specifically agreed otherwise, all information will be carefully made anonymous, and all the data on such original sources will be held as confidential and will not be distributed to others;
7. The resulting dissertation, with anonymous data, will be reviewed by a University teaching staff member and/or a University appointed external assessor, by the University moderators, and by external examiners;
8. Whilst an MSc Dissertation does not pass into the public domain, it is possible that the dissertation (with its data) may be used as a source for future research, including research work for publication;
9. Whilst summarised/ analysed data may be used in future research and/ or publications, your individual data responses will be retained only until the student completes their course and then destroyed.

This research has been favourably reviewed by the University's Biomedical and Scientific Research Ethics Committee, Approval Reference: REGO-2017-WMG-0649, dated: 13/06/2018.

Dissatisfaction with the conduct of this research may be referred to the person below, who is a senior University of Warwick official entirely independent of this study: Head of Research Governance, Research & Impact Services, University House, University of Warwick, Coventry, CV4 8UW; Tel: 024 76 522746; Email: researchgovernance@warwick.ac.uk

Appendix 3 – PIL

PROJECT TITLE: Application of Lean Manufacturing methods to a Marble Factory

NAME OF RESEARCHER: Enver Utku Tuzcu

I confirm that I have read and understood the provided Participant Information Leaflet (PIL) for the above project, and that I have had the opportunity to ask any questions about the research that I may have.

Further, I have been given a copy of the PIL which I may keep for my records.

I agree to take part in the above study and am willing to have my involvement in the interview noted.

Further, I have additionally agreed to have the interview electronically recorded.

I understand that my information will be held and processed to be used anonymously for internal publication for an MSc project, to be submitted for assessment for an MSc degree. I also understand that such anonymous data may be used for future research, including that for publication.

I understand that my participation is voluntary and that I am free to withdraw at any time up to the submission of the dissertation without giving any reason and without being penalised or disadvantaged in any way.

Name of participant .... Date ....

Signature ....

Appendix 4 – Current Inventory figures of the case company

PACKAGED STOCK								11.04.2018
STONI	SURFACE FI	LENGTH	WIDTH	THICKN	# IN PAC	# OF PACK	M3	M2
AF	POLISHED	160	30	2	64	3	1,8432	92,16
AF	POLISHED	120	30	2	50	12	4,32	216
AF	POLISHED	91,5	91,5	2	50	2	1,67445	83,7225
AF	POLISHED	91,5	45,7	2	40	14	4,683336	234,1668
AF	POLISHED	61	61	1,5	63	11	3,8679795	257,8653
AF	POLISHED	61	30,5	1,5	130	2	0,725595	48,373
AF	POLISHED	61	30,5	1,5	128	1	0,357216	23,8144
AF	POLISHED	60	60	2	50	97	34,92	1746
AF	POLISHED	60	60	2	50	8	2,88	144
AF	POLISHED	60	30	2	100	31	11,16	558
AF	AGED	61	61	3	33	1	0,368379	12,2793
AF	AGED	61	61	3	33	4	1,473516	49,1172
AF	AGED	61	61	3	33	1	0,368379	12,2793
AF	AGED	61	61	3	33	1	0,368379	12,2793
AF	AGED	61	40,6	3	66	4	1,9614672	65,38224
AF	AGED	61	40,6	3	66	2	0,9807336	32,69112
AF	AGED	61	40	3	66	1	0,48312	16,104
AF	AGED	61	40	3	66	1	0,48312	16,104
AF	AGED	61	30,5	3	66	2	0,736758	24,5586
AF	AGED	61	30,5	3	66	10	3,68379	122,793
AF	AGED	61	30,5	3	66	1	0,368379	12,2793
AF	AGED	61	30,5	1,5	130	2	0,725595	48,373
AF	AGED	45	15	1,2	370	1	0,2997	24,975
AF	BRUSHED	100	30	2	62	1	0,372	18,6
AF	BRUSHED	91,5	91,5	2	32	4	2,143296	107,1648
AF	BRUSHED	91,5	45,7	4	21	5	1,756251	43,906275
AF	BRUSHED	91,5	45,7	2	42	8	2,8100016	140,50008
AF	BRUSHED	61	61	3	33	9	3,315411	110,5137
AF	BRUSHED	61	61	3	33	5	1,841895	61,3965
AF	BRUSHED	61	61	3	33	1	0,368379	12,2793
AF	BRUSHED	61	61	2	50	3	1,1163	55,815
AF	BRUSHED	61	61	1,5	65	3	1,0883925	72,5595
AF	BRUSHED	61	61	1,5	65	1	0,3627975	24,1865
AF	BRUSHED	61	61	1,5	65	0	0	0
AF	BRUSHED	61	61	1,5	65	0	0	0
AF	BRUSHED	61	61	1,5	65	16	5,80476	386,984
AF	BRUSHED	61	61	1,5	65	1	0,3627975	24,1865
AF	BRUSHED	61	61	1,5	65	13	4,7163675	314,4245
AF	BRUSHED	61	30,5	4	50	3	1,1163	27,9075
AF	BRUSHED	61	30,5	3	66	16	5,894064	196,4688
AF	BRUSHED	61	30,5	3	66	24	8,841096	294,7032
AF	BRUSHED	61	30,5	3	66	13	4,788927	159,6309
AF	BRUSHED	61	30,5	3	66	1	0,368379	12,2793
AF	BRUSHED	61	30,5	3	66	4	1,473516	49,1172
AF	BRUSHED	61	30,5	2	100	6	2,2326	111,63
AF	BRUSHED	61	30,5	1,5	130	5	1,8139875	120,9325

AF	BRUSHED	61	30,5	1,5	130	15	5,4419625	362,7975
AF	BRUSHED	61	30,5	1,5	65	1	0,18139875	12,09325
AF	BRUSHED	61	30,5	1,5	130	5	1,8139875	120,9325
AF	BRUSHED	45,7	45,7	4	42	3	1,05259896	26,314974
AF	BRUSHED	45,7	45,7	1,5	112	1	0,35086632	23,391088
AF	BRUSHED	45,7	45,7	1,5	112	5	1,7543316	116,95544
AF	BRUSHED	45,7	30,5	1,5	160	22	7,359528	490,6352
AF	BRUSHED	60	60	2	50	3	1,08	54
AF	BRUSHED	60	30	2	100	16	5,76	288
AF	BRUSHED	60	30	2	100	25	9	450
AF	BRUSHED	60	30	1,2	164	1	0,35424	29,52
AF	BRUSHED	30,5	30,5	1,5	260	1	0,3627975	24,1865
AF	HONED	91,5	91,5	2	33	4	2,210274	110,5137
AF	HONED	61	61	1,5	65	4	1,45119	96,746
AF	HONED	61	61	1,5	65	12	4,35357	290,238
AF	HONED	61	61	1,5	65	14	5,079165	338,611
AF	HONED	61	61	1,5	65	18	6,530355	435,357
AF	HONED	61	30,5	3	66	4	1,473516	49,1172
AF	HONED	61	30,5	1,5	130	2	0,725595	48,373
AF	HONED	61	30,5	1,5	130	2	0,725595	48,373
AF	HONED	61	30,5	1,2	164	12	4,3937568	366,1464
AF	HONED	60	30	2	100	4	1,44	72
AF	HONED	60	30	2	96	8	2,7648	138,24
AF	HONED	60	30	1,2	168	4	1,45152	120,96
AF	HONED	45,7	45,7	1,5	112	5	1,7543316	116,95544
AF	HONED	45,7	30,5	1,5	160	8	2,676192	178,4128
AF	CRUSHED	61	10	3	180	1	0,3294	10,98
SANTA	POLISHED	61	30,5	1	192	1	0,357216	35,7216
SANTA	POLISHED	60	60	2	50	45	16,2	810
SANTA	POLISHED	60	30	2	100	35	12,6	630
SANTA	POLISHED	30	30	2	200	12	4,32	216
SANTA	AGED	61	61	3	33	0	0	0
SANTA	AGED	61	40,6	3	66	3	1,4711004	49,03668
SANTA	AGED	61	30,5	5	40	4	1,4884	29,768
SANTA	AGED	61	30,5	3	66	0	0	0
SANTA	AGED	61	30,5	3	66	0	0	0
SANTA	AGED	45	15	1,2	370	2	0,5994	49,95
SANTA	AGED	40,6	40,6	3	66	2	0,65275056	21,758352
SANTA	AGED	30,5	15,2	3	136	5	0,945744	31,5248
SANTA	AGED	30	15	3	260	1	0,351	11,7
SANTA	AGED	23	8	1,2	1500	1	0,3312	27,6
SANTA	AGED	163277	1	3	1	15	7,3474632	244,91544
SANTA	BRUSHED	120	60	2	25	6	2,16	108
SANTA	BRUSHED	91,5	45,7	2	40	16	5,352384	267,6192
SANTA	BRUSHED	80	40	3	4	3	0,1152	3,84
SANTA	BRUSHED	61	61	3	33	30	11,05137	368,379
SANTA	BRUSHED	61	61	2	50	32	11,9072	595,36
SANTA	BRUSHED	61	61	1,5	65	280	101,5833	6772,22

SANTA	BRUSHED	61	40,6	2	100	3	1,48596	74,298
SANTA	BRUSHED	61	30,5	4	50	15	5,5815	139,5375
SANTA	BRUSHED	61	30,5	3	66	197	72,570663	2419,0221
SANTA	BRUSHED	61	30,5	3	66	2	0,736758	24,5586
SANTA	BRUSHED	61	30,5	2	100	2	0,7442	37,21
SANTA	BRUSHED	61	30,5	1,5	130	214	77,638665	5175,911
SANTA	BRUSHED	61	30,5	1	200	4	1,4884	148,84
SANTA	BRUSHED	60	60	3	33	1465	522,126	17404,2
SANTA	BRUSHED	60	60	2	50	97	34,92	1746
SANTA	BRUSHED	60	60	1,2	82	30	10,6272	885,6
SANTA	BRUSHED	60	30	3	33	1	0,1782	5,94
SANTA	BRUSHED	60	30	2	100	25	9	450
SANTA	BRUSHED	60	30	1,2	164	188	66,59712	5549,76
SANTA	BRUSHED	45,7	45,7	4	40	4	1,3366336	33,41584
SANTA	BRUSHED	45,7	45,7	1,5	112	57	19,99938024	1333,29202
SANTA	BRUSHED	45,7	30,5	1,5	160	12	4,014288	267,6192
SANTA	BRUSHED	30,5	30,5	4	100	4	1,4884	37,21
SANTA	BRUSHED	30,5	30,5	1,5	260	2	0,725595	48,373
SANTA	HONED	91,5	91,5	2	30	2	1,00467	50,2335
SANTA	HONED	91,5	45,7	3	28	5	1,756251	58,5417
SANTA	HONED	91,5	45,7	2	56	13	6,0883368	304,41684
SANTA	HONED	90	30	3	40	1	0,324	10,8
SANTA	HONED	80	40	3	60	1	0,576	19,2
SANTA	HONED	61	61	2	50	2	0,7442	37,21
SANTA	HONED	61	61	1,5	65	43	15,6002925	1040,0195
SANTA	HONED	61	61	1,2	80	4	1,428864	119,072
SANTA	HONED	61	30,5	3	33	11	2,0260845	67,53615
SANTA	HONED	61	30,5	1,5	130	29	10,5211275	701,4085
SANTA	HONED	61	30,5	1,5	130	1	0,3627975	24,1865
SANTA	HONED	61	30,5	1,2	164	8	2,9291712	244,0976
SANTA	HONED	61	30,5	1	200	47	17,4887	1748,87
SANTA	HONED	60	60	2	50	38	13,68	684
SANTA	HONED	60	60	1,2	82	7	2,47968	206,64
SANTA	HONED	60	30	2	96	12	4,1472	207,36
SANTA	HONED	60	40	3	66	1	0,4752	15,84
SANTA	HONED	45,7	45,7	1,2	144	8	2,887128576	240,594048
SANTA	HONED	45,7	30,5	1,5	160	8	2,676192	178,4128
SANTA	KUMLAMA	61	61	2	50	1	0,3721	18,605
SANTA	CRUSHED	61	10,2	2	480	2	1,194624	59,7312
SANTA	CRUSHED	30	10	3	220	1	0,198	6,6
SANTA	CRUSHED	17	5	2	1470	2	0,4998	24,99
SANTA	CRUSHED	10	5	2	2470	1	0,247	12,35
SANTA	LINED	100	30	1,5	62	1	0,279	18,6
SANTA	LINED	23	8	2	1250	1	0,46	23
SANTA	HAMMERED	23	8	1,2	1500	1	0,3312	27,6
MYRA	RAW	30	30	3	64	4	0,6912	23,04
MYRA	POLISHED	120	60	3	20	15	6,48	216
MYRA	POLISHED	101,6	77,6	2	31	5	2,4440896	122,20448

MYRA	POLISHED	91,5	91,5	2	32	34	18,218016	910,9008
MYRA	POLISHED	91,5	45,7	2	40	38	12,711912	635,5956
MYRA	POLISHED	80	80	2	32	5	2,048	102,4
MYRA	POLISHED	80	40	3	64	14	8,6016	286,72
MYRA	POLISHED	61	61	1,5	65	2	0,725595	48,373
MYRA	POLISHED	61	30,5	1,5	130	4	1,45119	96,746
MYRA	POLISHED	60	60	2	48	130	44,928	2246,4
MYRA	POLISHED	60	30	2	100	1	0,36	18
MYRA	POLISHED	60	30	2	100	55	19,8	990
MYRA	POLISHED	30	30	2	200	5	1,8	90
MYRA	AGED	61	61	3	33	28	10,314612	343,8204
MYRA	AGED	61	40,6	3	66	13	6,3747684	212,49228
MYRA	AGED	61	30,5	3	66	38	13,998402	466,6134
MYRA	AGED	30,5	30,5	3	130	8	2,90238	96,746
MYRA	AGED	30,5	15,2	3	260	143	51,709944	1723,6648
MYRA	AGED	163277	1	3	1	51	24,98137488	832,712496
MYRA	BRUSHED	120	30	2	50	3	1,08	54
MYRA	BRUSHED	91,5	91,5	2	50	1	0,837225	41,86125
MYRA	BRUSHED	90	60	3	20	44	14,256	475,2
MYRA	BRUSHED	90	60	1,5	40	4	1,296	86,4
MYRA	BRUSHED	80	80	3	16	1	0,3072	10,24
MYRA	BRUSHED	61	61	3	33	2	0,736758	24,5586
MYRA	BRUSHED	61	61	1,5	65	6	2,176785	145,119
MYRA	BRUSHED	61	61	1,2	80	2	0,714432	59,536
MYRA	BRUSHED	61	30,5	3	66	8	2,947032	98,2344
MYRA	BRUSHED	61	30,5	1,5	130	6	2,176785	145,119
MYRA	BRUSHED	61	30,5	1,2	164	10	3,661464	305,122
MYRA	BRUSHED	60	60	3	33	6	2,1384	71,28
MYRA	BRUSHED	60	60	3	33	45	16,038	534,6
MYRA	BRUSHED	60	60	3	33	519	184,9716	6165,72
MYRA	BRUSHED	60	60	3	33	781	278,3484	9278,28
MYRA	BRUSHED	60	60	2	50	32	11,52	576
MYRA	BRUSHED	60	60	2	50	4	1,44	72
MYRA	BRUSHED	60	60	2	50	185	66,6	3330
MYRA	BRUSHED	60	60	1,2	82	4	1,41696	118,08
MYRA	BRUSHED	60	30	3	100	20	10,8	360
MYRA	BRUSHED	60	30	2	100	10	3,6	180
MYRA	BRUSHED	60	30	2	100	24	8,64	432
MYRA	BRUSHED	60	30	2	100	169	60,84	3042
MYRA	BRUSHED	60	30	1,5	76	1	0,2052	13,68
MYRA	BRUSHED	60	30	1,2	164	80	28,3392	2361,6
MYRA	BRUSHED	45,7	45,7	1,5	112	2	0,70173264	46,782176
MYRA	BRUSHED	30	30	2	200	8	2,88	144
MYRA	HONED	120	60	2	30	0	0	0
MYRA	HONED	120	30	3	41	8	3,5424	118,08
MYRA	HONED	100	65	4	15	2	0,78	19,5
MYRA	HONED	100	50	3	30	3	1,35	45
MYRA	HONED	100	50	2	40	3	1,2	60

MYRA	HONED	100	40	3	60	3	2,16	72
MYRA	HONED	91,5	91,5	2	30	6	3,01401	150,7005
MYRA	HONED	91,5	61	2	25	4	1,1163	55,815
MYRA	HONED	91,5	45,7	3	33	4	1,6558938	55,19646
MYRA	HONED	91,5	45,7	2	40	10	3,34524	167,262
MYRA	HONED	91,5	45,7	1,5	65	1	0,407701125	27,180075
MYRA	HONED	90	30	3	40	6	1,944	64,8
MYRA	HONED	90	30	2	100	2	1,08	54
MYRA	HONED	81,2	40,6	1,5	60	12	3,5604576	237,36384
MYRA	HONED	80	80	4	17	3	1,3056	32,64
MYRA	HONED	80	80	2	30	5	1,92	96
MYRA	HONED	75	45	5	44	1	0,7425	14,85
MYRA	HONED	70	50	3	30	1	0,315	10,5
MYRA	HONED	70	40	3	66	4	2,2176	73,92
MYRA	HONED	61	61	1,5	65	24	8,70714	580,476
MYRA	HONED	61	61	1,5	65	4	1,45119	96,746
MYRA	HONED	61	61	1,5	65	4	1,45119	96,746
MYRA	HONED	61	61	1,5	65	2	0,725595	48,373
MYRA	HONED	61	61	1,2	82	2	0,7322928	61,0244
MYRA	HONED	61	30,5	2	100	13	4,8373	241,865
MYRA	HONED	61	30,5	1,5	130	22	7,981545	532,103
MYRA	HONED	61	30,5	1,2	164	20	7,322928	610,244
MYRA	HONED	61	30,5	1	180	10	3,3489	334,89
MYRA	HONED	61	30,5	1	200	16	5,9536	595,36
MYRA	HONED	61	30,5	1	200	3	1,1163	111,63
MYRA	HONED	61	30,5	1	200	1	0,3721	37,21
MYRA	HONED	61	25	3	66	16	4,8312	161,04
MYRA	HONED	60	60	3	48	5	2,592	86,4
MYRA	HONED	60	60	2	48	57	19,6992	984,96
MYRA	HONED	60	60	2	48	11	3,8016	190,08
MYRA	HONED	60	30	3	66	69	24,5916	819,72
MYRA	HONED	60	30	2	96	15	5,184	259,2
MYRA	HONED	60	40	3	66	29	13,7808	459,36
MYRA	HONED	60	40	2	100	2	0,96	48
MYRA	HONED	60	30	3	66	6	2,1384	71,28
MYRA	HONED	60	30	1,2	164	2	0,70848	59,04
MYRA	HONED	50	50	2	120	4	2,4	120
MYRA	HONED	50	30	2	80	20	4,8	240
MYRA	HONED	45,7	45,7	1,2	144	15	5,41336608	451,11384
MYRA	HONED	45,7	45,7	1	168	7	2,45606424	245,606424
MYRA	HONED	45,7	45,7	1	160	11	3,6757424	367,57424
MYRA	HONED	45,7	30,5	1,5	160	2	0,669048	44,6032
MYRA	HONED	45,7	15,3	1	200	2	0,279684	27,9684
MYRA	HONED	40	40	3	30	4	0,576	19,2
MYRA	HONED	40	40	3	66	40	12,672	422,4
MYRA	HONED	40	40	1,5	112	24	6,4512	430,08
MYRA	HONED	40	20	1,5	224	4	1,0752	71,68
MYRA	HONED	30,5	30,5	1	360	3	1,00467	100,467

MYRA	HONED	30,5	30,5	1	360	14	4,68846	468,846
MYRA	HONED	30,5	30,5	1	112	1	0,104188	10,4188
MYRA	HONED	30	30	3	132	6	2,1384	71,28
MYRA	HONED	30	30	2	200	1	0,36	18
MYRA	HONED	30,5	15,2	1	720	4	1,335168	133,5168
MYRA	CRUSHED	60	10	2	204	2	0,4896	24,48
MYRA	HAMMERED	70	50	32	1	1	0,112	0,35
MYRA	HAMMERED	70	40	32	1	1	0,0896	0,28
MYRA	HAMMERED	61	30,5	3	66	8	2,947032	98,2344
PB	POLISHED	91,5	45,7	2	42	2	0,7025004	35,12502
PB	POLISHED	80	40	3	33	10	3,168	105,6
PB	POLISHED	61	61	1,5	65	27	9,7955325	653,0355
PB	POLISHED	61	61	1,5	65	8	2,90238	193,492
PB	POLISHED	61	61	1,5	65	4	1,45119	96,746
PB	POLISHED	61	30,5	1,5	130	4	1,45119	96,746
PB	POLISHED	60	60	2	48	3	1,0368	51,84
PB	POLISHED	60	60	2	48	26	8,9856	449,28
PB	POLISHED	60	30	2	96	1	0,3456	17,28
PB	POLISHED	60	30	2	96	19	6,5664	328,32
PB	AGED	23	8	1,2	1500	1	0,3312	27,6
PB	BRUSHED	100	30	2	60	1	0,36	18
PB	BRUSHED	61	61	3	33	4	1,473516	49,1172
PB	BRUSHED	61	61	3	33	3	1,105137	36,8379
PB	BRUSHED	61	30,5	3	66	2	0,736758	24,5586
PB	BRUSHED	45,7	45,7	2	50	10	2,08849	104,4245
PB	HONED	91,5	45,7	2	46	2	0,7694052	38,47026
PB	HONED	61	61	1,5	65	10	3,627975	241,865
PB	HONED	61	61	1,5	65	1	0,3627975	24,1865
PB	HONED	61	61	1,5	65	12	4,35357	290,238
PB	HONED	61	61	1,5	65	6	2,176785	145,119
PB	HONED	61	61	1,5	65	2	0,725595	48,373
PB	HONED	61	61	1,2	82	19	6,9567816	579,7318
PB	HONED	61	61	1,2	82	1	0,3661464	30,5122
PB	HONED	61	61	1,2	82	4	1,4645856	122,0488
PB	HONED	61	30,5	1,5	130	3	1,0883925	72,5595
PB	HONED	61	30,5	1,5	130	2	0,725595	48,373
PB	HONED	61	30,5	1,2	144	19	6,1083936	509,0328
PB	HONED	61	30,5	1	200	16	5,9536	595,36
PB	HONED	61	15,2	1,5	260	10	3,61608	241,072
PB	HONED	60	60	2	48	1	0,3456	17,28
PB	HONED	60	60	1,5	65	4	1,404	93,6
PB	HONED	60	40	2	100	4	1,92	96
PB	HONED	60	40	2	100	2	0,96	48
PB	HONED	60	30	2	100	7	2,52	126
PB	HONED	60	30	2	100	1	0,36	18
PB	HONED	60	30	2	96	2	0,6912	34,56
PB	HONED	45,7	45,7	1,5	112	3	1,05259896	70,173264
PB	HONED	40	40	3	60	52	14,976	499,2

PB	HONED	40	40	3	30	10	1,44	48
PB	HONED	30,5	30,5	1	360	2	0,66978	66,978
PB	HONED	30,5	30,5	1	360	3	1,00467	100,467
PB	HONED	30,5	20,3	1	360	1	0,222894	22,2894
PB	HONED	30	30	2	200	1	0,36	18
PB	HAMMERED	61	30,5	3	52	7	2,031666	67,7222
PB	BRUSHED	100	30	3	64	4	2,304	76,8
PB	CRUSHED	61	10,2	3	169	2	0,6309108	21,03036
PB	CRUSHED	10,2	10,2	2	272	1	0,05659776	2,829888
PB	CRUSHED	61	5	3	390	1	0,35685	11,895
PB	CRUSHED	17	5	2	1470	1	0,2499	12,495
PB	LINED	60	30	2	100	2	0,72	36
BEJ	POLISHED	60	60	2	48	4	1,3824	69,12
BEJ	POLISHED	60	30	2	96	4	1,3824	69,12
BEJ	POLISHED	40,6	40,6	1,5	130	5	1,607151	107,1434
						TOTAL	2570,398251	118670,593