IMPLEMENTATION OF LEAN WITHIN THE CEMENT INDUSTRY

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Abstract

Implementation of lean helps many organisations to improve their productivity and efficiency; on the other hand numerous organisations have failed to benefit from lean philosophy. The case of not achieving the expected results of implementing lean is not because of limitation of lean to specific organisations type; however the misconception of the lean philosophy is amongst the main failure's factors. The lean thinking was originated in the automobile manufacturing sector and it widely spreads within the discrete industries; however the today's challenge is to implement the lean philosophy within continuous manufacturing industries and different organisations regardless to the type, size, or mission of the applicant organisation. This has motivated the undertaken research to propose a standard generic transition steps which can be adopted by different organisations in order to become lean.

The cement industry is ideal example of the continuous industry sector and it will be used to demonstrate that the lean philosophy is applicable to all deferent organisation types. There are numerous challenges facing the cement industry in today's competitive environments; one of the major challenges is the capability of the cement industry to adopt and introduce the improvement approaches and techniques by which the overall enhancement can be achieved. The need for improving the efficiency of the cement production line is widely acknowledged in order to reduce the downtime rates, and satisfy high levels of market demand where the demand for cement is mostly second substance behind water. In response to this respect this thesis has investigated and addressed the implementation of the lean philosophy within the cement industry. The main contribution of this study is to convey the message to the decision makers that the lean philosophy is the proposed solution by which the

continuous industry and different organisation types can be improved through eliminating or minimising wastes and non-value added activities within the production line.

The developed transition steps have ability to:

- Understand the cement manufacturing process in order to identify value added and non-value added activities within production line through applying the process mapping technique.
- Determine and examine the interrelationships between the variables through developing of Cause-Effect matrix.
- Quantify the benefits obtained from the changing process within the cement production line through employing of the experimental design technique where novel approach has been developed by integrating the simulation modelling technique with Taguchi Orthogonal Array.

This research has led to observation that the cement industry can benefit from implementing lean philosophy once the organisation mission, aims, and objectives are clarified and communicated through all the organisation levels. Furthermore barriers and obstacles should be removed through changing the organisational culture, and empowering the people to be involved in identifying and problem solving process.

Acknowledgment

Praise to Allah who has guided me through and has given me the strength of the determination to carry out this work.

At finishing of this journey I realise that I did not do it alone; however I was surrounded by caring people who encouraged, exhorted, and supported me to pursue the race.

I would like to take this space to acknowledge them.

First I owe my profound gratitude to my family here in the UK and back in Libya for their unending patience, support, and love.

It would have been next to impossible to finish this research without help, guidance, and endless support from my supervisors (Prof. David Stockton and Dr. Riham Khalil) who have provided invaluable encouragements, advices, suggestions, and comments.

I must express my gratefulness to Mr. Gregory Webber in Ketton cement factory/ Stamford. UK and Mr Abd-Alwahid Alhrabi in the Suq-Alkhamis cement factory/ Tripoli, Libya.

Finally it is pleasure to thank my second family at the lean research group/ centre for manufacturing.

Declaration

I hereby declare that I am the sole author of this thesis and assure that it is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was completed under the supervision of Prof. David Stockton and Dr. Riham Khalil at the Faculty of technology/ De Montfort University

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Chapter 1: Introduction

Background:

The manufacturing's philosophy has witnessed fundamental changes since the elimination of craft production to be replaced by mass production system. New era has started when lean manufacturing perspective is introduced. The idea of lean production was originated at Toyota house in early 1950s. The main theme of lean philosophy is to use less but achieve more through eliminating or minimising non-value added activities and wastes within the system (Womack et al, 2003). Organisations are under pressure to reduce their cost, customer lead-time and cycle time, and increase their productivity and quality. Many organisations have realised the essential need to adopt the lean philosophy instead of the traditional mass production concepts in order to stay competitive and survive in the recent recession and global rivalry situation.

The undertaken research will attempt to show that the lean methodology is not only limited to specific type of organisations, but it can be applied successfully to all organisation types as long as the right transition path is applied effectively. The research here will study and develop standard steps which can be used as guidelines in implementation of lean methodology within different organisations. The cement industry's real-world data is used to examine the validity of the proposed methodology.

1.1- Problem statement:

The cement is mostly found everywhere in everyday life and it is hard to imagine a modern society without it. It provides the basic input to the construction industry which has major role among the modern global infrastructures and development processes.

Furthermore for period of time the national development was measured by production and consumption size of the cement (Pipilikaki et al 2009, Treloar et al 2001). The cement industry operates in virtually all countries around the world; however more than 70 percentages of the global cement are produced and consumed in the developing countries where the construction development is much higher pace than the developed countries (John, 2003). This industry has all the features to be a successful sector especially in some developing countries, where cheap fuel and energy are available in the oil producer countries e.g. Libya; however the problem is that the cement industry is under pressure to reduce the downtime, cycle time, inventories and batch sizes.

The cement industry is characterised by intensive energy and raw materials, large Work-In-Progress inventories, high breakdown levels, and the need to increase the productivity in order to meet high demands (Bahatty et al, 2004). The situation of not achieving the expectation of high machine utilisation and production rates, low breakdown rates, and trouble free operation processes within the cement production line has motivated the undertaken research to design an integrated framework by which the cement production line will be improved and enhanced.

1.2- Research aim and objectives:

The undertaken research proposes standard steps that can be carried out in lean transition which mainly adopted from the lean thinking. However the research here will undertake a novel step in integrating modelling system of the cement production line with Taguchi Orthogonal Array which will first investigate the different types of variability. The integrated method will be then used as a developed solution that can be applied to improve the production line’s performance measurements; i.e. it will help in conveying a message to the decision makers that the cement industry can be transformed from traditional mass production into lean firm.

The research aims will be accomplished through achieving the following objectives:

1- Understanding the cement manufacturing process.

2- Identifying different types of interrelationships between the variables which associated with the production line and their effects on the performance parameters.

3- Validating the obtained results.

1.3- Thesis structure:

Chapter 2 provides a literature and industrial review of the cement manufacturing process. It will start with illustration of the process mapping of the cement manufacturing process. Furthermore there will be a brief comparison between the four methods (wet, semi-wet, semi-dry, and dry) that adopted for making the cement. The dry method will be discussed in details, because it is the most adopted method within the modern cement factors around the world. Chapter 2 will address the main variables and factors that influence materials flow and efficiency within each sub-process.

Chapter 3 will give with a brief review about the industrial management and motivational theories. Then it will discuss the basic principles and concepts of lean manufacturing; furthermore a brief description of the wastes within the cement production line will be demonstrated. Chapter 3 will talk about different system-change initiatives and how organisations can benefit from implementing of complementary system and integrated framework in order to improve the efficiency and performance of the system. Barriers and roadblocks that may prevent or obscure the organisation to benefit and take advantages from lean implementation within their systems are become the last section of chapter 3.

Chapter 4 will review the different research methods. It will discuss and present a detailed description of the undertaken method that was developed to be the research methodology.

Chapter 5 will display and illustrate the results of the developed research method.

Chapter 6 will highlight the forces to change within the cement industry through providing of SWOT analysis. It will discuss the obtained results. Finally chapter 6 will identify the barriers and obstacles within the cement industry.

Chapter 7 will provide the main conclusions of the undertaken work.

Finally, opportunities for future work will be highlighted and mentioned in chapter 8.

Chapter 2: Cement Industry

Introduction:

In order to achieve comprehensible understanding of the cement industry features, and all effective factors and problems that may occur during the manufacturing process; this chapter attempts to give a clear picture of the cement production line. It will start by breaking down the different processes that compose the cement manufacturing process. The process mapping of cement industry takes place after receiving large quantities of limestone, chalk and clay. These materials are quarried, crushed, transported to the factory, pre- blended, and to be stored as the raw materials (Bahatty et al, 2004 and Hills, 2002). This chapter will discuss and examine some problems that may occur within the main and sub cement production line processes.

The cement industry is one of the oldest industries in the world. The demand for the cement has risen rapidly over the last decades to become the second substance after the water. The industry is high intensively of raw materials and energy with fuel accounting for 30-40% of the production costs. Briefly the cement industry can be summarised only into three main production processes: raw milling process, thermo-chemical process, and finish grinding process.

2.1- Process Mapping of the cement manufacturing process:

As mentioned earlier, the undertaken research starts with process mapping of the cement production line in order to achieve better understanding of what is happening in the production line. As mentioned by Anumba, (2006) process mapping is not only tool which demonstrates the links between input, output, and different activities within the manufacturing process.

Based on the work of (Mintus et al 2006, and Biege et al, 2001) the cement production process can be classified and as illustrated in Figure (2.1) either: wet, semi-wet, semi-dry, or dry.

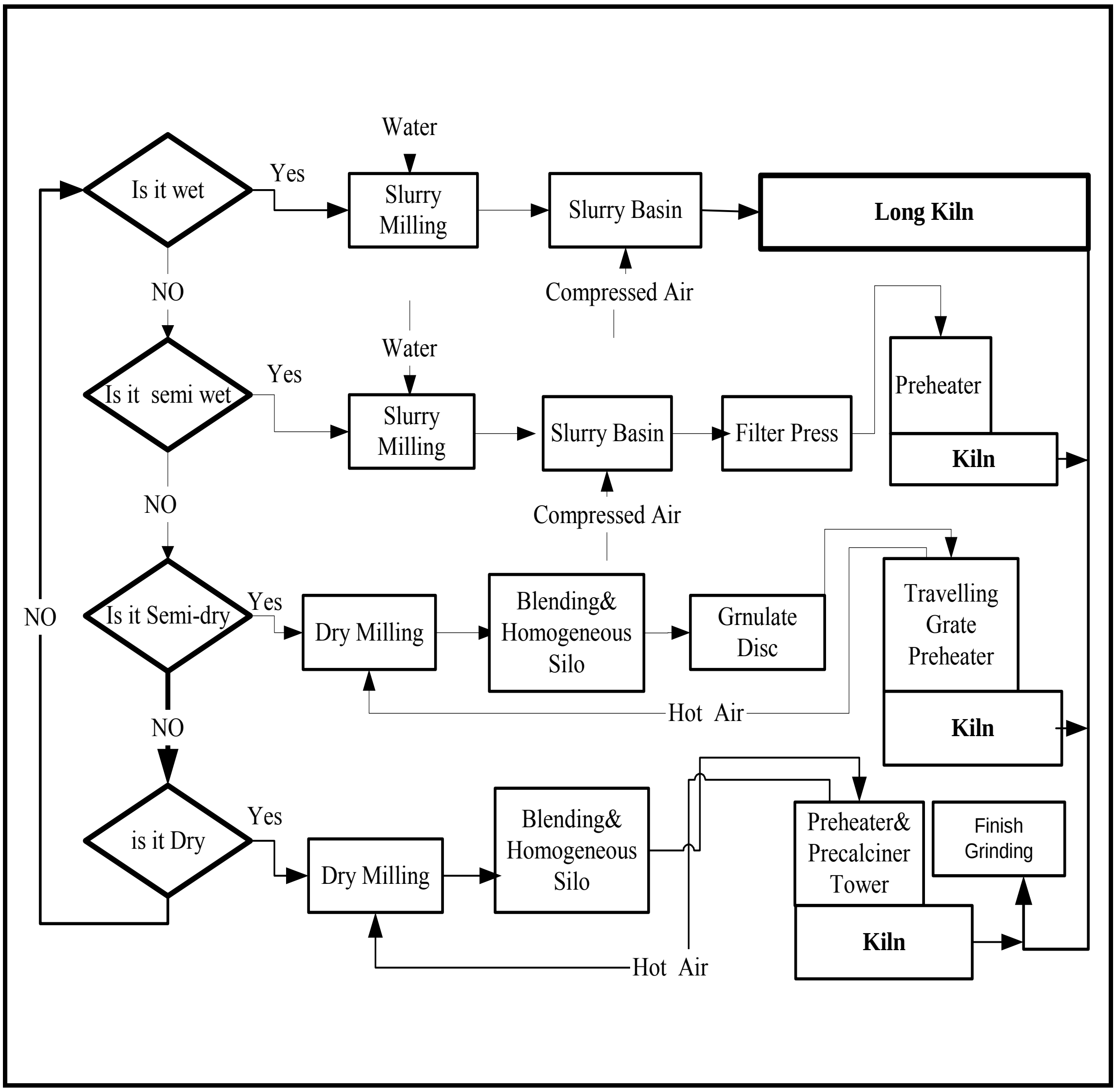

Figure (2.1): different Cement manufacturing processes.

2.1.1-Wet Process:

Mintus et al (2006) mentioned that prior to 1950 the wet manufacturing system was adopted as the main process within kilning systems. The wet process is adopted whenever:

a) the moisture is 30% or more by the weight of raw materials, or

b) when the pipelines are used to convey the raw materials to the cement factory which is some distance from quarries site.

According to (Worrell et al (2000) the advantages of the wet process can be summarised as:

i. Optimum blending and homogenising process: In the wet process, the slurry is blended and homogenised in a slurry basin. The raw materials (slurry) can be easily mixed using compressed air and rotating stirrers to achieve homogeneous component, and

ii. Low dust: Based on work of Utlu et al (2006) that the injection process of water has an important role to reduce the dust level during the raw milling stage. In addition wet kiln systems produce low levels of dust than the dry systems. The dust is produced because of blowing out situation of dry raw meal which is fed in counter path to the kiln exhausting gases Renfrew et al, (2005). While according to Szabó et al, (2006) that main disadvantages of the wet process is the low thermal efficiency, where large amount of energy is used for evaporating the slurry moisture content at kiln's drying zone.

2.1.2-Semi-Wet process:

Various developments have been applied to wet process aiming to reduce the amount of water within the fed meal. Several types of slurry filtration equipments are used to transform the slurry meal into filter cake; this process is known as semi-wet process. The key distinction between wet and semi-wet processes is the introducing of filtration stage within semi-wet process before conveying the fed meal into the kiln. The main purpose of the filtration stage is to reduce the energy's consumption. The slurry meal is dewatered by using of filter press forming filter cake, which is fed either to travelling grate preheater or direct to long kiln (Bech et al, 1998).

2.1.3-Semi-Dry process:

The semi-dry process was another result of evolving progression of the wet process. Travelling grate preheater includes flat inclined rotating pan known as (Granulating disc) is introduced, where the dry meal is dampened by adding 10-15% of water to form hard pellets of 10-20mm diameter before feeding to the kiln (Biege et al, 2001 and Ward et al, 1994). As a result of technological progression over decades; the dry kiln is adapted to be the main method to produce the cement. Nowadays most of the world cement is produced by using of dry production system aiming to increase the productivity and efficiency, and reduce production costs (Boe et al, 2005).

2.1.4-Dry process:

The dry cement production system consists mainly of three sub-processes which are: dry raw milling, dry thermo-chemical, and finish grinding, Figure (2.2). As the most modern cement factories implement the dry manufacturing process; therefore the dry manufacturing process will be the core of this research.

Process mapping was carried on the dry process production line to understand in details the different events, activities that occur in the three main dry process production line sub-processes. Variables and factors that control and influence the both sub-processes within the dry manufacturing process will be identified and named in (2.2). Furthermore (2.2) will discuss and highlight problems that may occur within the dry manufacturing process.

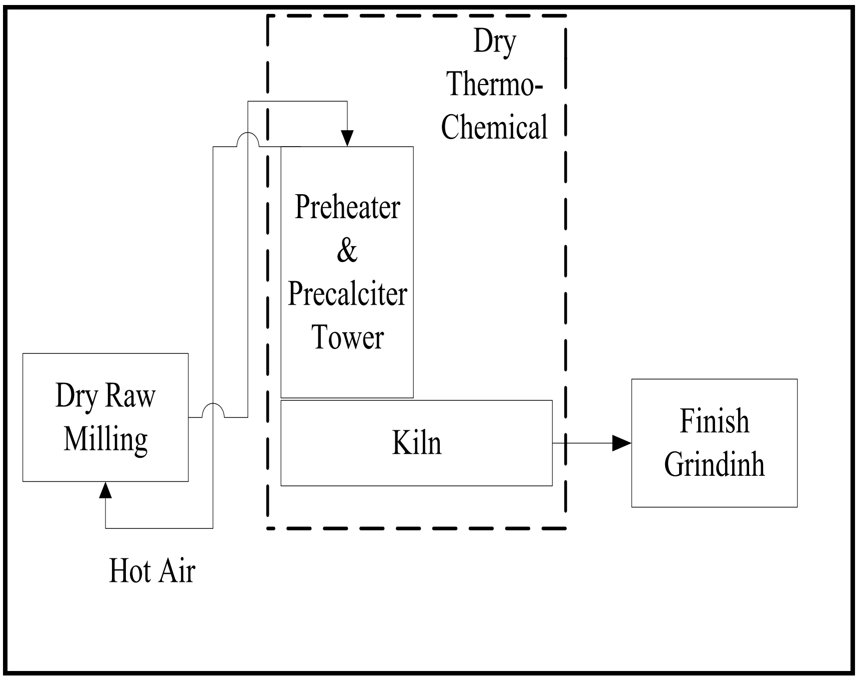

Figure (2.2): Dry cement manufacturing process.

1- **Dry Raw milling:**

It is mainly consisted of five sub-processes as it can be seen in figure (2.3).

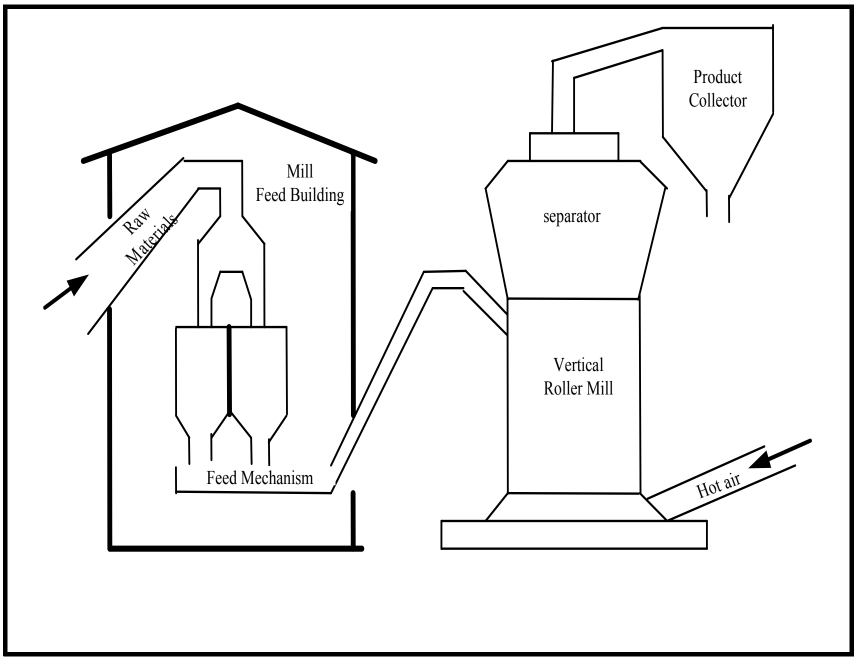

Figure (2.3): Closed Raw Milling Process (Vertical Roller Mill).

a) Mill feed building:

The main reason for using the mill feed building is to control the supply of the blended raw materials to different milling machines within the raw milling site (Conroy, 2009).

b) Feed mechanism:

Mechanical conveying systems are wildly accepted in cement factories rather than pneumatic conveying systems. Bucket elevators are the main type of the mechanical conveying systems that used for dry milling process because of

i. it is the most economical and reliable method,

ii. it has low operating and maintenance costs, and

iii. it has low environmental and safety risks (Pang et al 2004 and Pang et al 2005).

c) Vertical roller mill:

The Vertical Roller Mill (VRM) system has number of advantages over other mills. VRM has higher productivity, low consumption of the energy, and is more flexible for handling the wide variety of raw materials' specifications such as level of moisture and grind-ability (Folsberg, 1997). The feeder conveys the material into the centre of the rotating grinding table forming a bed on the table surface. Constant revolving motion of the table drives raw materials under the revolving rollers. The rollers are connected to hydraulic cylinders providing the pulverizing forces. High stream of air will dry any moisture within the raw materials and sweep up the fine particles to high efficiency separator, which located on the top of the mill unit. The fine particles will be separated and conveyed to product collector while the coaster particles are re-circulated to the table for regrinding (Simmons et al, 2005).

d) Separator:

As mentioned above the reason for using the separator is to classify and return the oversize particles of the raw materials.

e) Product collector:

It is a container where fine powder of raw materials accumulated before transmitted to the raw mill silos, blending and homogenous silos.

The milled raw materials are mixed together in the raw mill silos forming homogeneous raw meal with required chemical compositions. The homogenising process controls the raw meal's quality before fed into the kiln. According to (Bhatty et al 2004, Bond et al 2004 and Bond et al 1998) that the most modern cement factories use the funnel flow system by which the blending process can be achieved through reclaiming process of different layers that represent the whole raw meal. The discharge materials forms inverted cone cutting whole layers. This homogenisation process is known as gravity approach.

2- Dry Thermo-Chemical Process:

The thermo-chemical process is in the heart of the cement industry and any malfunction that may occur within this process will affect the whole production line. Furthermore any improvement will be reflected at the quality and costs of the product. The dry thermo-chemical process has witnessed significant incremental developments during the last decades. Kiln production rate depends on the heat energy input from the burning zone. Accordingly, an extra combustion chamber is installed between the lower preheater cyclone and the rotary kiln in order to improve the kiln productivity, and clinker quality. This type of kiln is known as dry kiln with Preheater and Precalcinre (Lin et al 2009).

Nowadays; most of cement factories implement dry kiln with Preheater and Precalciner system because of:

a) This will reduce the consumption of fuel and energy and the thermo load at kiln burning zone resulting in increasing the lifetime of the kiln lining. It has more thermal efficiency than other systems, i.e. the process of heat transferring is more efficiently resulting in improvements of kiln capacity and productivity, and

b) the short kiln with small ratio of length to diameter (L/D) has vital impacts on improvement of clinker quality by producing small alit crystals (Boe et al 2005).

Figure (2.4) illustrates the dry thermo-chemical process in details as:

The raw meal is fed at the top cyclones while the hot kiln gases rise up from the bottom cyclones. Feed meal will be preheated and partially hydro-carbonated during heat exchanging process between the raw meal and kiln exhausted gases. The meal will be suspended with the hot gas in order to achieve optimum results of heat exchange process prior entering the kiln. The suspension time of the feed meal is controlled by air flow rates and number of preheater cyclones (Nielsen, 1991). The temperature of feed meal is gradually rising while passing down through the preheater tower. The feed meal is completely decarbonised at point **(A)** prior entering the kiln. Appearance of clinker nodules starts at point **(B)**, and the final structure of clinker nodules is achieved when the raw meal reaches its peak temperature at burning zone point **(C)**. Finally, the hot red clinker nodules are discharged from the lower end of the kiln point **(D)** which called nose ring.

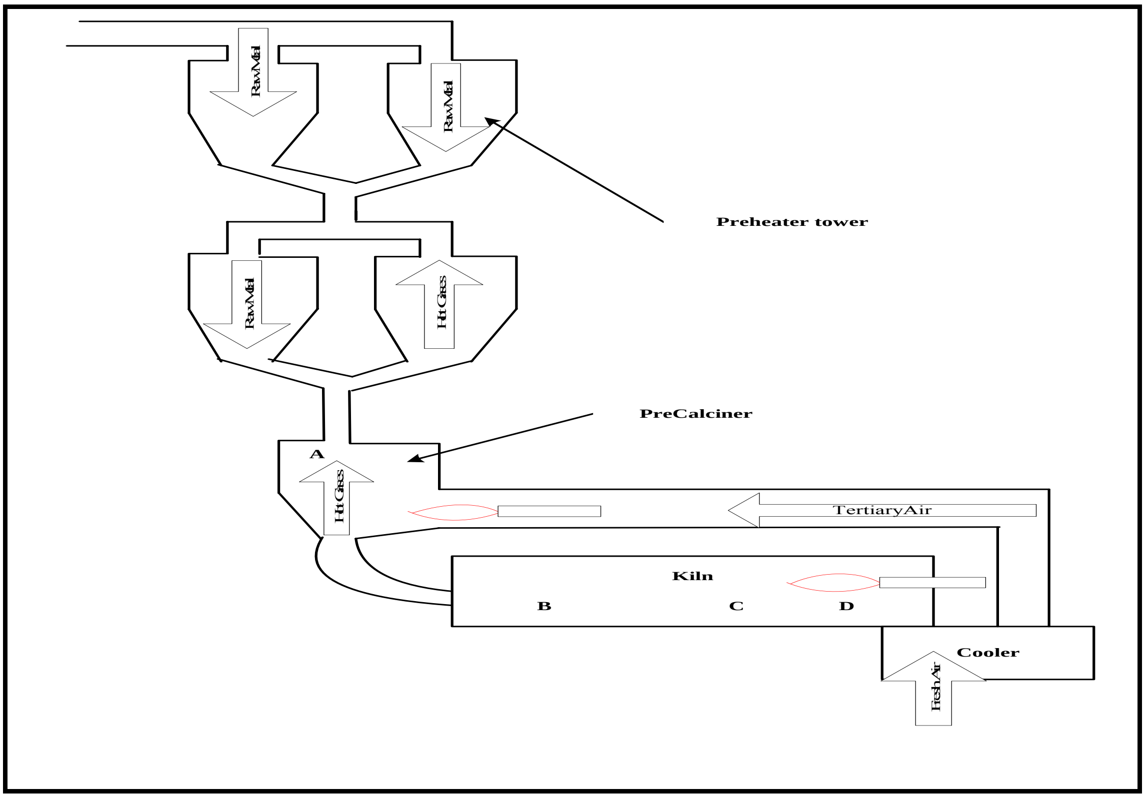

Figure (2.4): Dry Thermo-Chemical Process (Kiln with Preheater and Pre-Calciner).

The clinker is passed to the cooler in order to:

a) Suspend any unnecessary chemical reactions of the clinker, which may affect the product quality,

b) recovery the heat from exhausted gases either as combustion air in the kiln or for drying the raw materials, and

c) reduce clinker's temperature to suitable degree for following stages (Matthias 2005).

The cooler is an integral part of the kiln system and has a crucial influence on product quality and whole line performance. The theory of clinker cooling stage is based on the heat transfer principles between the air and clinker bed. Therefore, the cooling rate is based on the uniformly distribution of clinker bed, air flow rate, and conveyor speed. The clinker cooler has vital impact on heat consumption and energy consumption through supplying hot air to the kiln. Moreover it affects Kiln downtime and reliability, Clinker quality, overall productivity and efficiency, and Production costs (Bentsen et al 2005, Chavarro et al 2003, and Klotz 2000). Most of the modern cement factories combine a reciprocating grate cooler with their kiln systems, which namely consists of three sections.

- **i.** Inlet section: It is an inclined static grate to assure the clinker is distributed uniformly for promoting the heat transferring process,
- **ii.** moving grate plates for conveying the clinker, and current of fresh cold air is supplied in order to reduce the clinker temperature and using the recovered heat in kiln combustion chamber, and
- **iii.** outlet section; where extra cold air is applied for additional reduction in the clinker temperature before delivered to the clinker store through transfer hopper (Klotz, 2000).

2.1.5- Finish Grinding Process:

Stacking the clinker into the store becomes as milestone of starting the second stage of cement production process. According to (Schott et al 2003) that, the Clinker is mainly stacked in Clinker storage silo which consists of cylindrical hall with cone shaped roof. The clinker is loaded through the cone and discharged in systematic manner to centre-gravity discharge tunnels in order to obtain well-blended stock. A proximately 3% - 5% of gypsum are added to the clinker forming fed meal for the finish milling process. Clinker grinding is an intensive energy process by consuming about 44kwh/tone which equivalents to around 40% of the total used electric energy. Therefore; any improvement progress leads to vital impacts on the whole line performance.

Simmons et al (2005) illustrated that, the closed ball milling system is the traditional circuit for grinding the clinker. It is mainly consists of feed system, ball mill, elevator, and separator. Figure (2.5) demonstrates the elements of the finish grinding system.

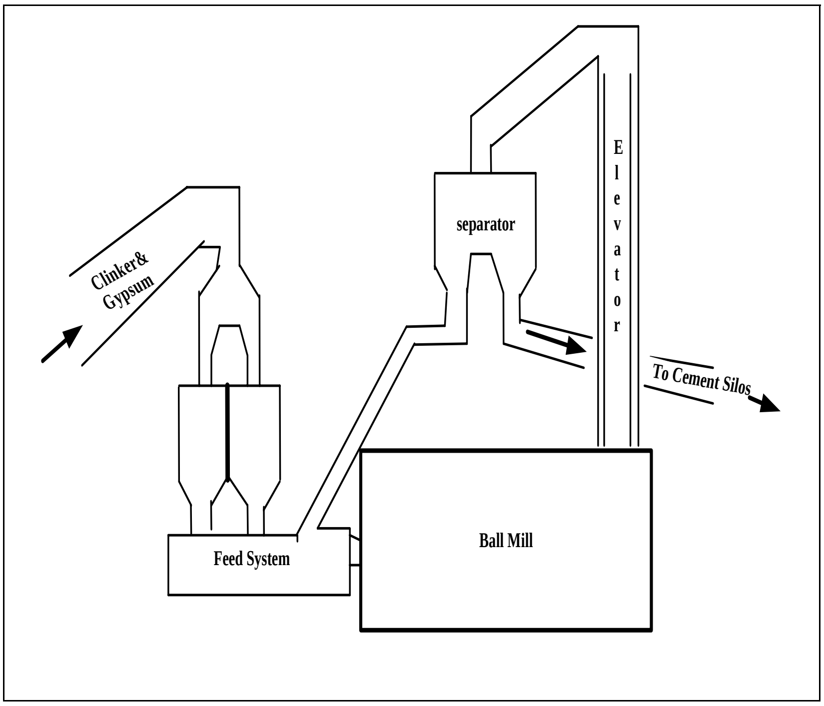

Figure (2.5): Closed finish grinding Process (Ball Mill)

1- Feed system:

Terembula (2004) has mentioned that the feed system for closed ball milling system consists of bins, weight-feeders, and belt conveyors. The feed system provides a supply of the clinker to the mill.

2- Ball mill:

It is a rotary horizontal cylindrical drum, which divided into two chambers and charged up to 35% of its volume with different sizes steel balls (grinding media). Large balls are used within inlet chamber, while small balls in second chamber. Fine powder (cement) is obtained from the collision between the clinker nodules and steel balls because of drum's revolving motion Fang et al (2009), Bond et al (2000).

3- Elevator:

It is used to lift and transfer the powder to separator. Hamdani (2000) has stated that the mill discharge is conveyed to the separator using a bucket elevator.

4- Separator:

Fortsch (2006) has demonstrated that the productivity and overall efficiency of the ball mill have improved since the High Efficiency Separator (3rd generation) have implemented in late 1970s. The outlet air stream from rotor cage separator conveys the fine particles to the electro-filter precipitator (EP), then to the cement silos. The coarse particles are re-circulated back and mixed with the fresh feed for further grinding.

According to Strasser (2002), Radziszewski et al (1993), and Mishra et al, (1992) that the high efficiency separator has the ability to improve the productivity and the overall efficiency of the finish milling system by: reducing the power consumption, improving the product quality, and increasing the system productivity through reduction of rework percentage

Finally, that grey finely powdered material (cement) is obtained and while waiting for packing and shipping it will be stored in cement silos.

2.2- The cement manufacturing process's variables and factors:

There are number of variables and factors which control the overall performance of the cement manufacturing process such as:

1- Materials properties:

Cement industry is a continuous process manufacturing which is characterised by intensive materials consumption. Therefore, any little improvement or adjustment in the properties of the raw materials will enhance the process performance and the plant overall. Different properties of raw materials have vital impacts on the cement production line's performance:

a) Moisture:

Brundiek et al (1997) have emphasised that the energy amount and cycle-time that needed for drying and processing the raw materials are proportional to the moisture contents. For example more energy is needed to produce enough hot air in order to dry the raw materials with high moisture. Therefore the moisture content affects and controls the productivity and performance of the raw milling process,

b) Material compositions:

According to Bhatty et al (2004), and Hills et al (2002) that limestone (Calcium Carbonate), Calcium Sulphate, Magnesium Silicate, and Clay are the main raw materials which are used to produce the cement. Each raw material has a variety of chemical and mineralogical compositions. The product quality and processing times are extremely variable and depends on the compositions. Therefore, Kizilaslan et al, (2003, and Bond et al, (2000) have emphasised on the role and the main purpose of the raw materials quality control in order to accelerate the sintering reactions and decrease the needed energy to burn the raw meal. The material quality control process can be achieved by adding corrective materials such as: Bauxite (Aluminium ore), Laterite (ferric and aluminium oxides), and Sand stone.

In addition, Schott et al (2004, and Kizilaslan et al (2003) have stressed the need for homogenisation of raw materials. Process of mixing the raw materials is required to obtain specific physical and chemical properties. Schott et al, (2003) have defined the blending and homogenisation process as: a creating of required specific physical and chemical properties of raw materials by mixing and integrating certain quantities of those materials.

Number of problems can occur and arise within the cement production line as a result of materials compositions variations. For example

i. Corrosion problems: Tao et al (2007) have classified the corrosion within this process into two groups. First, cold corrosion which can be occurred because of oxidation state. The cold corrosion is resulted from the reaction of the equipment surface with water and oxygen. Secondly, chemical corrosion which can be occurred as a result of the chemical reaction between the corrosive gases and equipments. Biege et al (2001) have mentioned that the raw materials and fuel are counted as the major sources of the corrosive gases such as: sulphur oxides (SO_x), calcium chloride ($CaCl_2$), and nitrogen oxides (NO_x). Corrosion situation affects the performance of raw milling system by increasing the breakdown rates and reducing the equipment availability and reliability Jansen et al, (2003).

ii. Build-up formation of materials and rings forming: Sulphur**,** Chlorine, and alkali components may accumulate at the cold zone of the kiln obstructing the raw meal flow leading to unstable operation. Number of factors can control and keep values of these volatile components at minimum levels such as: chemical properties of raw meal and fuels, Oxygen rates, and flame characteristics Jansen et al, (2003).

c) material grind-ability:

Csöke et al (2003) have mentioned that material's grind-ability can be classified into three main categories such as: easy to grind, normal to grind, and hard to grind. Materials with easy grind-ability need short residual time in the mill. On the other hand longer residual time is needed for hard grind-ability materials. Murthy et al (2000) have demonstrated the proportional relationship between the grinding force and required energy, and hardness of the material. The consumption of electric energy and process time are proportional to the material hardness. Material grind-ability affects and governs the equipment reliability and performance. Folsberg (1997) have illustrated that some units of raw milling and finish grinding systems are exposed to variety levels of wear. For example components such rollers, mill table, mill wall lining bricks, and grinding media can be exposed to high rate of wear as a result of direct contact with rigid materials. Gouda, (2003) has stated that variation in clinker grind-ability may be resulted from change in clinker properties due to fault in cooling process or long storage times. The materials grind-ability factor is expressed in term of specific electric power (KWh) that consumed for grinding one ton of final product.

d) product fineness (Blaine number):

Works of Touil et al (2005) and Panigrahy et al (2003) have illustrated the impact of the product fineness on the product quality, processing time, separator speed, and regrinding rates. High Blaine number needs the separator to run at high speed.

e) particles size of the materials:

Opoczky et al (2004), and Gordon (2004) have reported that longer processing time is needed for grinding large particles whilst small sizes are ground easily in short time. Grinding and blending processes of large particles consume more energy and longer processing times. Therefore the large chunks of raw materials should be crushed and pre-grinded into the standard sizes. The formation case of large crystals should be prevented during the thermo-chemical process Choate, (2003).

f) material burn-ability:

The burn-ability of feed meal has vital role on required energy and kiln efficiency. Terry, (1994) has arranged the material burn-ability as easy, normal, or difficult to burn. The burn-ability is depends on many factors such as: homogeneity, component composition, and fineness of feed meal. Moreover; Blanco et al, (1996) have highlighted the interrelationship between feed meal burn-ability and clinkering process properties such as: residence time, maximum temperature and pressure, and cooling rate.

2- Materials flow rates:

Palmer et al (1998) have shown that the high rate of feed meal is combined by dramatic reduction in mixing speed of raw materials. The efficiency of heat transfer process between hot gases and solids will be decreased.

The reduction of mixing speed and heat transfer efficiency will result in clinker quality and energy consumed. Consequently; the flow rate of feed meal should be optimised in order to enhance the kiln performance. The optimum filling range is between 12%-17% of kiln capacity. Any value exceeds 13% can impede the heat transferring process between raw meal and hot gases.

Derobert et al (1996) has emphasised that the ball mill must neither under-filled nor overfilled with clinker. On one hand, at low filling situation the mill wall is exposed to balls tumbling. The breakdown rate increases because of the direct collision between the wall and balls. The direct collision between the balls will result in wear of mill lining and the balls themselves; furthermore low breakage rate situation consumes more energy for low productivity. On the other hand the overfilling situation requires an additional energy and process time. The overfilling reduces the grinding efficiency, because of dampened contact between balls and clinker nodules. Consequently; the optimal clinker filling level has to fill all voids sufficiently covering the grinding media (balls); however clinker filling level should not exceed 25% of the total ball mill volume Touil et al, (2005).

3- Materials bed thickness:

Gordon (2004) has emphasised that the raw milling system should operated at its maximum capacity for minimising the production costs. The theory of grinding process at VRM is based on pulverising the raw materials between the rotating rollers and table. Therefore, regular and uninterrupted feed rate of sufficient bed depth must be fed into the mill avoiding any threats of grinding process performance. An insufficient bed thickness of raw materials increases the production costs and results in high rollers wear rate, which caused by direct contact between rollers and the table. On the other hand excessive bed depth minimises the compression force between layers and resulting in production costs. Accordingly, the maximum mill capacity is proportional to table and roller diameters, and rollers number Tamashige et al, (1991).

As it has mentioned at (section 2.1.4) the theme of cooling process is to exchange the heat between hot clinker nodules and cold fresh air; hence the cooling process will be quicker at little layers of clinker nodules rather than at cumulated thickness clinker bed. On the other hand the processing time will be longer resulting in higher production costs; as a consequence an optimum clinker bed thickness has to be achieved Klotz, (2000).

4- Air flow rates:

According to Roy et al, (2003), and Roy (2002) in order to improve the milling process performance the air flow rate should be kept in minimum values. They should be minimised to the necessary levels for drying the raw materials and sweeping up fine particles.

According to Gordon, (2004) in order to minimise the electric energy; the air flow rate should be limited to the necessary amount for lifting the grinded materials to the separator. The minimum values are vital factor for reducing the separator wear rate and consumed power by mill fan. On the other hand Ito et al, (1997) have proven that the productivity of grinding process is proportional to the air flow rate.

Brundiek et al, (1997) have reported that the mill table of raw milling system could be exposed to thermal stress as a result of passing hot stream of kiln exhausted gases. These gases are used to dry the raw materials and reduce the moisture level. Moreover, excessive flow rate will consume unnecessary energy sweeping up coast particles which expedites the separator wear. Constant and adequate levels of air flow rate must be optimised to prevent any overloading and thermo-defect situations which can be caused by an inadequate air flow.

Based on the work of Senegačnik et al, (2007) kiln hot gases pass upward in counter-current to fed meal flow. The hot gases have vital role in controlling thermo-chemical process. These gases can be divided into two categories: primary air, and tertiary air Rasul et al, (2005).

a) The primary air is the fresh air that supplied into kiln's burning zone forming the right mixture with fuel for combustion process.

b) The cooler exhaust gas which known as (Tertiary air) is utilized in attempt of heat recovery process. The tertiary air is supplied to the Precalciner's combustion chamber. Temperature of the tertiary air is controlled by clinker bed thickness, and cooling air flow rate at cooler and cooler speed.

The high flow rate of kiln exhausted gases cause suspension situation of the fed meal at the Precalciner. Consequently excessive quantity of raw meal must be supplied in order to maintain steady materials flow rates; however dramatic pressure drop cross is caused by increase status of materials recirculation within the kilning system resulting in energy consumption, clinker quality, production cost, and efficiency coefficient. Therefore, in order to enhance the overall performance an optimal flow rate of air has to be maintained Vaccaro, (2006).

Benzera et al (2001) have emphasized that the air flow rate has essential impact on the milling process and separator efficiencies. Excessive flow rate of air increases the recirculation rate of coarse particles resulting in reduction of grinding efficiency, and rising wear rates of balls and separator.

5- Re-circulation rate:

Typically 15-25% of materials are returned to the mill for regrinding. The rework ratio is proportional to air flow rate and rotational speed of the separator. Accordingly, amount of rejected coast particles is increased as the air flow rate is increased with combination of high speed of the separator. Over-processing situation is resulted from excessive re-circulation rate Folsberg, (1997). Based on work of Zarger, (1995) that high regrinding rate has negative effects on the productivity and production costs. The optimal values of returned materials to the mill's inlet can be achieved through adjusting the air flow rate. Moreover, the recirculation rate is a function in the separator cuts/ speed based on production fineness (Blaine number). The optimum recirculation rates for ordinary cement are in range of 10-30% of the whole feed materials.

6- Separator speed:

The separator rotational speed controls the fineness of the produce. In other words there is proportional relationship between the targeted product fineness and separator speed; furthermore separator speed affects the amount of the rejected coast particles Ito et al, (1997)

7- Pressure inside the mill:

The mill loading state is indicated by the differential pressure between inlet and outlet mill points. Case of overloading is indicated by very high differential pressure. While, very low differential pressure indicates under-loading. Therefore, the mill pressure should by maintained in certain level in order to avoid high levels of rejection and vibration operating conditions which is caused by very high pressure. Moreover, the feeding process maybe blocked when the differential pressure reaches very low readings Salzborn et al, (1993), and Tamashige et al, (1991). The differential pressure is governed by the flow rates of air and feed materials.

8- Mill speed:

As mentioned in (section 2.1.5) that the breakage is resulted from the tumbling action. Conventionally; the mill should rotate at maximum speed for achieving high breakage rate within low energy consumption rate and minimum processing time. Cleary (2003) has shown that the maximum mill speed is governed by its critical speed and it should operate within the optimum rotational speed, which occurs at range 70-85% of the mill critical speed. The critical speed is the speed when the balls stuck to the wall and not fall back due to high centrifugal force resulting in dramatic reduction of grinding efficiency. According to Mio et al,(2004) there is an opposite proportional relationship between mill diameter and its rotational speed for example as the mill diameter increases as it runs in low speed.

9- Mill Length- Diameter (L/D) Ratio:

L/D ratio of the ball mill has vital influence on energy consumption and mill productivity. In large L/D ratio the grinding process will be unaccomplished because of the balls are partially migrate along the mill length. Accordingly the mill will have long processing time and insufficiently materials mixing producing fine product. On the other hand small L/D ratio has perfectly mixing materials manner producing coaster product in shorter processing time. Schnatz (2004) has proven that the optimal L/D ratio is within the range of 2-3.5.

10- Mill % ball charging:

The grinding mechanism within ball milling system is based on the collision between the clinker nodules and balls. Initially; there is proportional relationship between the ball charging percentage and the clinker quantity can be fed into the mill. There are number of considerations such as the maximum design mill loading, and an additional electric energy which is needed to grind extra quantities of clinker. On one hand, reduction in mill loading is combined with reduction of consumed electric power. Nevertheless under loading has negative impact on specific power consumption and it has not be less than 25% of the mill volume. Therefore; Partyka et al, (2007) has stress that the mill should be charged with balls up to 35% by volume.

11- Flame Characteristics:

Gupta (2000) has reported that flame characteristics within kiln burning and calcination zones have a vital impact on the clinker quality, processing time, breakdown time, and equipment performance. Controlling of the flame features is extremely essential in order to avoid the main troubles that may occur and improve the whole line performance. According to Aloqaily et al, (2007) there are a number of key factors have to be optimised in order to control and adjust the flame characteristics; these key factors are.

a) Flame temperature: is accounted as one of the most main key factors which control the whole production line and specially the thermo-chemical process. Therefore, the flame temperature has to be optimised through controlling and adjusting the primary air flow rate and Oxygen concentration. For example high levels of primary air flow rates reduce the flame temperature resulting in clinker quality and production costs. An excessive primary air flow rate means high heat loos by carrying extra heat to the preheating zone, then released to the atmosphere. On the other hand low tertiary air temperature reduces the flame temperature at Precalciner. Overheating and forming rings situations within the kiln are proportional to flame temperature at low levels rate of primary air and high Oxygen concentration levels. These situations affect the product quality and breakdown time. Consequently; the primary air flow rate, tertiary air temperature, and Oxygen concentration have to be controlled and adjusted accurately in order to optimise the flame temperature Miller et al, (2004), Renfrew et al, (2004), and Salmento et al, (2004),

b) flame length: Vidergar et al, (1997) have reported that short burning zone minimises the heat loss from shell and the kiln far end. The short intensive flame improves the clinker quality through rapid processes of heating and cooling the clinker i.e. it prevents attempt of any undeserved crystallising process. On one hand extremely short and intensive flame causes an overheating case at the burning zone, while the kiln in general is cooled. On the other hand long flame gives slow heating up and cooling processes, which produce large clinker crystals. These large crystals affect the quality and grind-ability of the clinker. Long flame produces more ring formation. The flame length is reduced due to rising levels of primary air flow rate and Oxygen concentration, reduction of tertiary air temperature, and faster mixing process of fuel and air, and

c) flame stability: stable flame has vital impact on the thermo-chemical process. Flame stability is important to achieve high clinker quality and process efficiency. Unstable flame results in product quality and breakdown time, through rapid heating and cooling of the kiln refractory. Flame stability can be adjusted by controlling the flow rate of primary air and amount of chlorocarbon within the kiln Kumaran et al, (2007).

12- Volatile concentration:

Kurdowski et al (2004) have illustrated that case of build-up is resulted from increase in concentration of volatile constituents at the preheater during the process of heat exchange at high evaporating pressure. Volatile components will evaporate and swept-up along the preheater, where they start to condense at low temperature zone forming internal circuit in the kiln. Continual evaporation and condensation increases the concentration of volatile components until the internal circuit is closed. Volatile constituents are key factor of clinker quality, kiln reliability and capability, and overall performance. In order to optimise the kiln performance, the concentration of volatile components should be kept at minimum levels.

13- Residence time of raw meal within the kiln:

It is the required time by the raw materials to travel along the kiln. Mujumdar et al (2007) have proved the vital role of slope and rotational speed of the kiln for determining the length of residence time.

14- Cooler speed:

The speed of the cooler is indicated by number of strokes per minute (stroke/min). Gagnon (1997) has mentioned the vital role of the cooler speed during clinker cooling stage; as the cooler speed increases as the clinker bed is reduced. This will enhance the heat exchange process between the clinker nodules and cooling air; however high wear level is recognised at over speeding cooler. Therefore the cooler speed has to be adjusted to the optimised level.

15- Cyclones number:

Based on (section 2.1.4) the cycling time of feed meal at preheater tower is proportional to the number of preheater cyclones. The suspension time of the raw meal at preheater with six cyclones will be longer than that one within four cyclones. The heat transfer process will be more efficiently at high number of cyclones.

2.3- Summary:

The cement industry is ideal example of the continuous process manufacturing where the traditional mass production system is adopted in order to produce, accumulate, and move thousands tons of materials between the work areas.

The nowadays challenge is to change the cement industry from traditional mass production into more effective production system aiming to increase the productivity, overall performance, and capacity utilisation to meet high marker demand. The cement industry is forced to reduce the production costs and delay times in order to take advantages in the global competition environments.

The above sections have shown the interrelationships between the variables and factors which control the cement industry. Consequently, interrelationships within the cement production line elements have to be considered for avoiding undesirable results through any attempt to improve an individual performance parameter regardless to the interrelationships with the others.

Next chapter will highlight and address the main concepts and aspects of lean journey. In addition it will discuss the main barriers that may impede the changing process.

Chapter 3: Lean Manufacturing Overview:

Introduction:

In the twentieth century two major manufacturing revolutions have been introduced. Both revolutions have been developed at the automobile sector. The first revolution was mass production. In the 1900s the demand for cars has raised dramatically, and the automobile sector has become very competitive. Craft production has dominated the automobile sector; in fact using of the craft production was inadequate to manage the high demand at that period. In that era, very high qualified workers were spending a long time to produce a single vehicle. This has affected prices and annual production rate of vehicles. The weakness of the craft production system has inspired Henry Ford to develop the first manufacturing revolution (mass production). The mass production has provided sufficient number of identical cheap vehicles.

The second revolution was Toyota Production System (TPS). Lean was a new thinking way which has grew up at the Toyoda family company (Toyota house). Lean philosophy was driven by some main ideas as: customer values, eliminating non-value added activities and wastes, and work force ideology by involving the people in the production process to become a part of the community.

This chapter will illustrate and discuss the journey to be lean. It started by brief historical review of the main manufacturing events. Then it demonstrates lean principles and concepts, and lean problem solving methods. Finally it argues deferent methods of lean implementation and the main barriers that may occur during the implementation process.

3.1-Manufacturing management:

Modern manufacturing started in 1911 when Frederick Taylor published his theory Scientific Management. Scientific management has perfected the idea of pin factory which was included within the work of Adam Smith. In 1776 Adam Smith published "the Wealth of Nations". The theme of (pin factory) was to divide and associate labours with a specific production activity. Furthermore, Smith has mentioned that individuals act and contribute within the production process based on self-interests (Liker, 2004).

The principles of scientific management were centralised on application of scientific methods to manpower's management in order to improve and optimise productivity. These principles can be summarised as:

1- Developing scientific methods for each task in order to standardised the work and replace rule-of-thumb work method.

2- Scientifically selection, training, and development of workers rather than passively leaving them to chose their tasks and train themselves,

3- Cooperation between management and workers to ensure that the scientific procedures are followed in order to accomplish the specific task, and

4- Equate dividing of tasks between workers and managers, where each group are responsible for specific activities within the organisation (Taylor, 2006).

Implementation of these principles had improved the productivity dramatically and had substantial impacts on industry sector; however attention was drawn towards the negative side of Taylor's theory, which included impersonal organisational environment. The main criticism of this theory was that Taylor treats human resources as machines who are only motivated and satisfied by money. In addition, situations of complexity and isolation have grown, because of departmental strategy. Number of researchers has been guided by these concerns in order to study and examine differences and the conflicts between human behaviours and management missions **(**Hopp et al, 2001 and Anderson, 1983)**.**

For example (Ratnayake 2009) has reported that the Hawthorne studies have illustrated how work groups provide either effective support or horrific resistance to schemes of increase output which have planned by bureaucratic management. This study has argued that social factors had a positive influence on work behaviour and human not only respond to classical motivations as suggested in the scientific management approaches; however workers were interested in the rewards and punishments motivations. The Hawthorne study suggested that organisation to be considered as social system rather than a formal arrangement of functions only.

The Hawthorne study has concluded that:

a) High productivity is resulted from work satisfaction,

b) social factor has a strong influence on motivation,

c) sufficient levels of communication and cooperation among the organisation will increase the productivity, and

d) money and management are not the most effective motivational factors.

These studies added much to the knowledge of human behaviour in organisations Hawthorne studies have created pressure for researchers to explore and examine new motivational manners instead of traditional once (Baker 1999, and Arai 1998).

Numerous motivational theorists have been published, each has described and analysed the motivational states from different approaches. Some theories view the motivation as generalised drive state without any specific direction or aims. While others preserve motivational states being specific to particular drives and needs. Therefore, motivations must be analysed in terms of specific goals and direction. People differ in their responses to the motivational state according to their needs and satisfactions for example what motivates one person might not necessarily motivate another. Furthermore, what motivates one person at one time may not motivate him at a different time. Involvement and process improvement team are the main factors for making the transition into lean organisation easy and successful.

By the end of the First World War the manufacturing's philosophy has witnessed fundamental changes, since the elimination of craft production to be replaced by mass production system. Henry Ford has developed the concepts of mass production in order to produce large quantities of standardised goods. By using mass production system in his car assembly lines, Ford has become able to produce cars in high volume at very low costs. Mass production system characterised by producing high volume / low variety products using expensive inflexible machines and unskilled people (Holweg 2006, Duguay et al 1997).

3.2- Lean as a management approach:

After World War II new era has started when lean manufacturing perspective is introduced. The idea of lean production was originated at Toyota house in early 1950s.

According to Burkitt et al, (2009) the Toyota Production System (TPS) was a new thinking way and engineering approach which concerns about continuous improvement of the organisation. The Toyota Production System (TPS) aims to smooth flow of materials, eliminate wastes, improve quality and productivity, achieve operation flexibility, and reduce the production time. In addition the new thinking methodology has introduced the work force idea which aims to involve workers in processes of the improvement, problem identifying and solving, and decision making.

3.2.1- Lean Manufacturing Principles:

Womack et al (2003) have summarised the principles of lean manufacturing into five basic principles which are:

1- **Customer Value:**

   The production process should be defined and analysed with respect to customer values and satisfactions; the customer can be internal or external. Customer value can be defined as how the customer predicts and perceives the product or service that offered by the organisation. Whilst, customer satisfaction means how the customer utilises and benefits from these products and services. Analysing value is the starting point for any production process. The production activities need to be created in such a way to eliminate and minimise the wastes and non-value added activities (Shah et al, 2007).

2- Value Stream:

Value Stream illustrates the flow of material and information within the production system. The first step of this principle is creating of current state map (the currently way is used to provide service or product) and compare it with the future state map (the future operating way after improvement). Value Stream mapping tool is used in analysing and highlighting all non value added activities such as delay, excess stock, work in progress, moving, sorting, and long lead times (Hines et al, 1997),

3- Flow process:

Adoption of continuous flow principle will eliminate all types of wastes and obstacles that interrupt flow of the material or process. The continuous flow approach reduces the lead-time, processing time, and overall production costs. Availability of materials, tools, operators, and machines are essential factors for successful flow continuously system (Womack et al, 2003and Mohsen et al, 1992).

4- Pull system:

In Pull system customer demand controls and governs the flow of production through the production line. This principle aims to eliminate overproduction, handling, and produce to stock situations. Scheduling process in pull system is based on actual consumption and demand rather than theoretical forecasted scheduling process which associated with push system. In other words, pull system means only to produce the right requested quantities of the right quality in the right time. Kanban: it is a tool to achieve the pull principle. Kanban is a singling system to pull materials or product through the production line. This tool aims to provide the material or product when they are requested by next workstation or the customer. It aims at achieving Just-In-Time manufacturing system (Lee et al, 2003).

5- **Perfection**:

Since the customer values have been defined, non-value added activities were eliminated, and philosophy of continuous process and pull system are adopted through correct implementation of the above principles. It is time to implement the fifth lean principle which aims at continually improvement. Elimination of all wastes will result in enhancing of the overall performance, and reducing the cycle time and production costs (Ahlström et al 1996).

3.2.2- Wastes in Lean Manufacturing:

Lean manufacturing is a process management philosophy. Lean production system aims to produce products or services through using the minimum levels of everything such as minimum capital investment, minimum human efforts, and minimum wastes.

The key element of the lean strategy is to develop learning system that has the ability to identify and distinguish between the value added activities and wastes. Lean philosophy aims at enhancing the flow- rate of materials by eliminating or minimising the non-value added activities which can be listed as:

- ***Overproduction**:* It is a process of producing goods either more than the needed quantity or before the requested time. An extra inventory and raw materials, unnecessary work, and unbalanced material flow are accounted as a key symptom of overproduction waste (Bicheno, 2000).
- ***Transportation:*** any unnecessary transfer or movements of components or materials is defined as transporting waste (Hicks, 2007).
- ***Waiting***: Delay time occurs whenever time is not used efficiently. Waiting waste can be determined as the period of time when neither movement nor add value activity has been applied to the component or materials resulting in high levels of inventories and Work In progress between workstations (Persoon et al, 2006).
- ***Inventory:*** Inventory waste is resulted from accumulating unnecessary quantities of raw materials and Work In Progress to comply just in case logic. Work In Progress (WIP) can be defined as unfinished product, which is stocked between different production stages and workstations. According to lean philosophy principles; WIP is symptoms of hidden problems within the imperfect system. High levels of WIP are classified as muda which should be eliminated or minimised. Unnecessary inventory tends to raise production costs because it requires additional handling and space, and masks the real roots of problems components,

work-in-progress and finished product not being processed (Carreira, 2005).

- ***Motion***: It is any unnecessary activities (motions) that the operator engages in for handling or monitoring actions. These activities include bending, stretching picking-up, and moving. Unnecessary motion is classified as kind of waste because it influences quality and productivity (Bicheno 2000).
- ***Over-Processing****:* High rates of overproduction, defects items, or excess inventory will result in redundancy operations such as: reprocessing, recirculation, storage and handling (Liker, 2004).
- ***Defects****:* Process of inspection, rework, or repair of services and products called waste of correction process. Waste of defects can be described by high levels of rework and scrap, and increase level of rejected and returned products. Correction wastes occur because of: poor product design, lack of process and quality control, unreliable equipments and unskilled operators, and unbalanced inventory levels. Total Productivity Maintenance (TPM) is one of methods by which defects and scrap wastes can be eliminated (Kempton, 2006).

3.3- Performance Measurements:

Based on work of Folan et al, (2005) the identification of key performance parameters forms the foundation upon which the achievements will be obtained. The performance measurements provide the required timely feedback by which the successful implementation of lean manufacturing concepts can be indicated and proved. The performance measurements provide the essential links between organisation objectives, customer values, and lean transition Lohman et al (2004), Johnston et al (2003), and Kennerley et al, (2003).

Based on work of Folan et al, (2005) the selection process of an appropriate performance measurement system is critical to success. Not selecting the right performance measurements can produce counterproductive and obstruct the lean journey. Neely et al (2005), Melnyk et al (2004) and Neely et al (2001) have summarised a list of guidelines which can be used to select the suitable set of performance parameters in order to avoid any obstruction:

1- Performance measurements must be directly related to the firm strategy, aims, and objectives in order to avoid any misaligned and uncertainty of the measures. i.e. the parameter has to measure and identify gap between actual performance and expectations.

2- Fully understanding of process functionality that has to be achieved in order to identify sources and collection methods of the required data which will be used to evaluate and correct the candidate performance.

3- Measures must be selected, agreed, and acknowledged through all firm levels including the customer values and satisfaction to acquire the needed support and commitment from the all involved people, and to prevent any miscommunication.

4- Each parameter should be simple, visible and easy to quantify providing clear and fast feedback which enables the decision-makers to monitor, control, and correct the performance (Hauser et al, 1998).

5- Identification of factors and variables that affect and control the performance and their interrelationships (Suwignjo, 2000).

3.4- Implementation of Lean:

Lean is a powerful systematic and structured methodology for finding, solving, and preventing the performance problems through tracking-back approaches in order to find the main hidden roots of existing wastes. Implementation of lean philosophy can generate superior operational and financial improvements within all systems. The lean philosophy has been originated and associated with manufacturing industry. However lean methodology has been implemented successfully within different organisations worldwide rewarding amazing results regardless of type, size, and mission of the candidate system.

According to Neely et al (2000), and Harrison et al (1995) all deffernt organisations share the common incorporated characteristics which can be summarised as:

- **Input:**

  Inputs mean resources such as machinery, raw materials, capital, and people.

- **Process:**

  Processes become the second element; a proper sequence of actions and steps must be accomplished providing product or service that meets customer demands and expectations.

- **Output:**

Organisations are classified according to their outputs. The organisation that produces intangible products called service organisation such as health care, education, and insurance companies. While the organisation that produces tangible items known as manufacturing organisation.

Ahlstrom (2004) has concluded that the journey of implementing lean philosophy requires great determination and guidance to change toward the better; numerous works and articles have described several manners for managing lean transformation within organisations. For example Womack et al, (2003) have mentioned eight steps as guidance through the transmutation journey; these steps are:

1- **Finding of a change agent:**

   The agent could be either external or internal. This agent should believe and give people confidence that the organisation will be changed toward the better. In addition the change agent has to have the ability and courage to cause changing actions and to stand against resistance attempts to lean transformation within the organisation.

2- **Obtaining the knowledge:**

   A fully understanding of lean techniques, tools and their applications becomes a fundamental factor within lean journey. Continuous achievement of enough knowledge is obtained through participation in improvement activities.

3- Finding or creating a crisis:

The crisis situation within the system is a best opportunity to implement lean. The ideal start of lean implementation is determined through identifying and revealing the weakness of current process.

4- Neglecting of the grand strategy for the moment:

Wastes elimination and minimisation should be become the priority to any organisation that seeks to implement lean. This means the initial beginning of lean implementation should start by eliminating non-value added activities and waste everywhere within the organisation regardless of the business mission and strategy.

5- Mapping value streams of the current state:

All processes and activities within the system's current state have to be mapped in order to obtain visual image of the whole value added and non-value added activities. The value stream mapping illustrates the flow of materials and information. In addition it highlights all wastes within the system.

6- Beginning as soon as possible with an important and visible activity:

The successful implementation should start with the most important area or activity which performing very inefficiently. The change agent should start with these activities to ensure immediate and visible results.

7- **Requesting immediate results:**

Immediate improvement within process is one of the most critical features of lean journey. The immediate improvement gives positive feedback which can be employed as motivation and amass support for adoption of lean within the whole system.

8- **Expanding the scope at earliest opportunity:**

The successful lean implementation is measured by the changing rate within the organisation. This means once the immediate improvement is achieved within a certain area or part of the value stream, it is essential to implement and spread the change to the remaining activities in order to improve the whole system.

On the other hand Allen et al, (2001) have argued that the lean implementation process can be divided into three main stages such as:

a) **Preparation stage:**

It is a fundamental starting stage of any successful process of lean implementation. Preparation stage means identifying and determining of missions, aims, objectives and area or activities that need to be improved. Recognising the need to change within the organisation, finding the change agent, and establishing the improvement team are accounted as the main steps of the preparation stage (Bhasin et al, 2006),

b) **design stage:**

Process mapping of system's current state is the first step of this stage in order to study and examine all activities and areas within the organisation. Visual stream mapping highlights all non-value added activities and wastes. In addition it analyses the system in order to determine all possible opportunities for future improvement. Planning the change becomes the final step of the design stage, where the detailed implementation plan need to be prepared and fully described in order to achieve the future vision of the organisation (Atkinson, 2004), and

c) **implementation stage:**

A specific area or part of value stream should be chosen to be as a pilot project in order to implement lean. The selected part or activity has to be important to the organisation giving immediate positive feedback. The positive feedback will be used to obtain the required support from decision makers and employees in order to expand lean philosophy through the whole system. The new system state should be evaluated and validated in order to identify all possible opportunities for future improvement (Chaneski, 2003).

As it can be seen there are numerous approaches of lean implementation. However the undertaken research attempts to propose a general improvement path which can be used by all organisation types.

3.4.1- Modelling of Lean:

Davis et al (2007) have reported that since several decades the simulation modelling has become a very popular analysis approach which can be applied within a wide variety of disciplines such as service domain, production lines, health and care firms, and social sciences.

Computational modelling technique can significantly contribute to a high-performance product development system. The simulation techniques provide the decision-maker with a quick feedback on ideas, result in a faster convergence of designs and ensure integration among different modules (Dennis et al, 2000). The appropriately use of simulation technique can strongly contribute to identifying and solving problems at a faster rate (Carley, 2002). Fowler (2003) has mentioned that the simulation model is able to create causal structures and analyse real-world organisational behaviours in order to identify sources of variation, wastes, and problems that may occur within the system. The simulation technique provides a powerful digital modelling methodology and helps to identify the right improvement opportunity within the firm (Cho et al 2005).

According to Law (2005), Wang et al (2005), and Robinson et al (1995) the features of successful simulation model can be summarised as:

1- The simulation model has to represent the actual activities and processes of the applicant organisation through using the real-world data.

2- The simulation model has to capture the casual interrelationships between the organisation components.

3- The simulation model has to be able to identify specific wastes and problems that may occur within the organisation, and

4- The simulation model has to be able to validate the corrective actions through analyse different scenarios and comparing the obtained results with the expected or desired once.

In 1960s Geoffrey Gordon has developed the Discrete Event Simulation (DES) technique at the IBM house (Gordon, 1978). Discrete Event Simulation (DES) is a modelling methodology which can simulate sub-processes, and activities as a series of chronological events. Discrete Event Simulation (DES) model can be developed in order to investigate and identify the causal relationships and hidden root causes of wastes and problems (Banks, 1999).

According to works of Banks et al, (2000), and Law et al (2000) there are several concepts of Discrete Event Simulation modelling approach such as:

- System: a collection of entities cooperate together in an interconnected manner to fulfil the overall aim,
- model: it is an conceptual presentation of the hierarchy construction of the candidate system demonstrating all mathematical or logical interrelationships which describe the system in terms of processes, activities, sets, events, state, entities, delays, and attributes,
- system state: a collection of variables which contain all the required information and data in order to describe the candidate system at any time,
- entity: any object or element of the system which requires precise demonstration within the model,
- attributes: the properties of a candidate entity, i.e. the properties of the job routing, a waiting machine, or customer a waiting,

- list: a collection of permanently or temporarily entities ordered logic such as; first in first out fashion,
- event: an immediate occurrence which changes the system state such as an arrival of new customer,
- event notice: a record of an event occurrence including the event type and exact occurrence time,
- event list or Future Event List (FEL): a list of any future event notice based on first occurrence ordered fashion,
- activity: a statistical distribution indicates the length of specified time duration such as arrival or service times,
- delay: an unspecified time duration which is not known when it begins or ends, and,
- clock: a variable presents the simulated time.

3.5- Beyond Lean Manufacturing:

There are number of system-change initiatives whose scopes extend beyond the production line to be deployed across the whole organisational functional aspects in order to achieve customer satisfaction (Cusumano et al, 1998). All the system-change initiatives share the same general characteristics as customer values, continuous improvement, continuous flow of material and information, human management, increase throughputs, reduction of costs, and elimination of wastes and non-value added activities (Koskela, 2004). An integrated combination of these approaches within systematic framework will aid the firms to accomplish the overall concepts. The major accepted system-change initiatives are:

3.5.1- Kaizen method:

According to Khan et al (2007), and Manos, (2007) that the Kaizen method is based on philosophy of continuous incremental and sustainable improvement culture which achieved through involvement of all the people within the organisation. The Kaizen strategy is the start-point of the successful lean Journey, which focalises on eliminating waste and non-value added activities and improving productivity and quality (Brunet, 2000).

Five key elements form the fundamental of Kaizen implementation method which are:

1- **Teamwork:**

   Empower and motivate the people to build teamwork who are responsible for implementing, monitoring, and measuring of the kaizen strategy (Styhre, 2001).

2- **Selection of activity or section:**

   Identify specific activity or area upon which the Kaizen will be implemented (Brunet et al 2003).

3- **Wastes identification:**

   Develop current and future states in order to identify muda and non-value activities within the specifics elected activity or organisation area (Soltero et al, 2002).

4- **Suggestions for improvement:**

   Plan changing ideas to achieve the future state (Elsey et al, 2000).

5- **Tools identification:**

Identify the suitable tools and methods by which the future state will be achieved (Chen et al, 2002).

3.5.2- Just In Time (JIT):

Organisations are forced to reduce lot sizes, inventories, and lead-times, production costs, and enhance the overall performance. The edge to achieve these objectives is the implementation of Just-In-Time production philosophy. The JIT system is the approach by which the organisations can deliver right items at right time in right quality (Klassen, 2000).

The critical principles for successful implementation of JIT system are:

1- **People involvement, training, and education:**

The successful implementation of JIT depends on the establishment of a communicative working environment to ensure all the people involvement. Good training and education programs are basic elements for flexible multi-skilled employees who are responsible for implementing the successful JIT system (Mould et al, 1995).

2- **Supplier relations:**

Integration good relationships with suppliers are important components which ensure continual flow of right quantities of material in the right time. Working together and sharing the beliefs with the supplier will eliminate the inventory wastes and improve the quality (Kumar, 2010).

3- **Waste elimination:**

The key element of the JIT is to produce only the requested quantity by which the overproduction waste will be eliminated. Furthermore the primary aim of the JIT is continual reduction and elimination all wastes forms (Low et al, 2008).

4- **Kanban or pull system:**

The pull system responds to actual demands instead of dependence on forecasting and estimation strategy (Liker, 2004). Kumar et al (2007) have reported that the Kanban system aims to eliminate the inventory wastes through scheduling and controlling the production and WIP.

5- **Uninterrupted work flow:**

The JIT philosophy concerns about continuity of work process without any interruption. The smooth flow leads to minimise the WIP, lead-time, and production costs (Low et al, 2008).

6- **Total quality control (TQC):**

Quality at source is a vital requirement for successful JIT system; it is concerns about assuring of producing the right product first time. The total quality control aims to achieve zero defects system in order to eliminate and minimise scrap and rework levels, and to enhance the productivity and overall performance (Ghosh, 1994).

3.5.3- Total Productivity Maintenance (TPM):

According to Chan et al, (2005) the Total Productive Maintenance TPM is a well-established method which aims to improve equipment reliability and efficiency rates, eliminate defect wastes, minimise process variations, and reduce production costs. These objectives can be achieved through identifying the root causes of failures and downtimes, maximising the length of the time period between failures (Mean Time To Failure), and involving and empowering people of all levels within the organisation (Ireland et al 2001 and Blanchard 1997). McKone et al (2001) have emphasised the contribution of the TPM into manufacturing performance improvement through enhancing the firm capability to identify and resolve problems; furthermore TPM aids in improving organisational culture and eliminating traditional departmental barriers between maintenance and production people.

According to Bamber et al (2000), and Ahmed et al (2005) that the TPM system comprises the following elements:

1- **People development:**

   Training and developing people have become the main objective of the TPM. According to Prouty (2006), and Mouss et al (2004) well organised and planned training programs must be available to ensure required levels of knowledge and skills are provided to improve workers performance. People should to be trained well in order to avoid unnecessary downtime and malfunctions, and improve productivity (Binninger, 2004).

2- **Documentation:**

   Documentation records of monitoring, control, and maintenance activities.

3- **Regular maintenance:**

   Scheduled and planned regular equipment maintenance aiming to reduce breakdown rates and enhance the equipment utilisation. The TPM stresses that the implementation of systematic maintenance scheme is a necessary component which has vitally important role within the organisations. Bris et al (2003) have emphasised the role of routine maintenance activities such as inspection, tightening, oiling, and cleaning within the preventive process of failures and defects which may be caused by malfunction equipments.

4- **Housekeeping keys:**

Implementation of housekeeping keys (5S) in order to improve the interior environment. According to Eti et al, (2004) that the housekeeping functions (5S) can be listed as:

a) **Sort (Seiri)**- identifying the necessary materials and tools in the working area,
b) **Straighten (Seiton)**- unnecessary materials and tools should be removed from the working area,
c) **Sweep (Seiso)**- routine maintenance and cleaning-up activities have to be performed to the working area,
d) **Standardise (Seiketsu)**- work and process should flow documented standard rules and regulation, and
e) **Self discipline (Shitsuke)** - discipline standardisation through implementation of the above steps and make them as a part of everyday task.

Al-Muhaisen et al (2002) have reported that costs of the maintenance activities in the cement industry are about 20-25 percent of the total production costs; furthermore they stressed the vital role the maintenance system to prevent failures, and enhance the overall. Numerous researchers have attempted to enhance maintenance system within the cement industry. For example Eti et al, (2006) have emphasised the needs for an appropriate maintenance system which maintains high performance by the reduction of unplanned down-time and inventory, and reduces the maintenance time instead of relying on reactive maintenance procedures. Stephens et al (2004) have discussed the opportunity of applying Automatic Downtime Monitoring strategy (ADM) within cement industry. The automatic downtime monitoring strategy has the ability to determine the Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR); furthermore it has the capability to monitor and analysis failures of the equipments using Pareto 20/80 chart.

3.5.4- Total Quality Management (TQM):

Isaksson (2006) has defined the Total Quality Management as a management philosophy which concerns with the continuous high-quality improvement, less rework, improve the productivity, and customer satisfaction. The TQM is integrated combination of statistical quality and management tools which aims to eliminate wastes and improve the organisational overall performance (Sriparavastu et al 1997, and Yeung et al 1997).

There are critical success principles which need to be considered in order to achieve successful implementation of TQM; these principles are:

1- **Management commitment:**

   It is the most important principle of successful TQM implementation. All the managers should demonstrate their commitments to prepare, understand, review, and monitor all activities of waste elimination and quality improvement to ensure the achievement of organisational mission and vision (Arditi et al, 1997). The managers need to communicate and spread principles and strategies of quality through the whole organisation levels in order to create new organisational culture. The new organisational culture concerns about sharing the values and beliefs; furthermore it aims to establish teamwork ideology through motivate and encourage all people to control, manage and involve in problem solving and decision-making processes (Chiu, 1999). The new culture attempts to improve the communications through elimination of departmental barriers (Maughan et al, 2005),

2- Training and education:

People education and training is a significant factor for any meaningful quality improvement (Mathews et al, 2001). People need to be trained in the quality concepts and tools in order to identify and solve quality problems, and participate to achieve the organizational goals and objectives (Harrington, 1995). An appropriate education and training programme provides adequate knowledge and skills to the organisation to adopt strategy of prevention rather than detection of problems (Chaudhry et al, 1997),

3- Customer satisfaction:

Understanding and consideration of the customer voice is a vital principle of the TQM by which the organisation can take competition- advantages (Forza et al, 1998). The effective addressing of the customer values and needs will help the organisation to design, build, and operate its system to produce the right goods at the first time (Zairi, 2002).

4- Continuous improvement:

The incessant changes in customer values and the external circumstances force the organisation to continual attempt to improve the quality of its products and processes in order to survive in the threatens global computational environments (Shea et al, 1995).

3.5.5- Theory Of Constraints (TOC):

In the mid 1980s Goldratt has developed the theory of thinking processes to enable the managers to achieve high performance of the system. TOC is a technique focusing on profit improvement through organisational change process (Lubitsh et al, 2005). Theory Of Constraints has stated that each system has its own constrains which control and limit the system from enhancing its performance. Drum-Buffer Rope (DBR) is the application of TOC in production systems. DBR aims at improving the production line through optimising of the weakest link, the constraint, or drum (Mabin et al, 2001). The main theme of DBR is that within any production line there is one or more limited resources, which control the overall throughput and the whole system should be scheduled regarding to the constraint. The DBR consists of three fundamental elements such as:

- **Drum:**

  It is the production rate (bottleneck) of the heavily loaded workstation within the production line. The bottleneck can be defined as: any constraint or obstructer that impedes an even flow rate of materials within the system.

- **Buffer:**

  It is the duration of material flow rate that is needed to prevent any problem occurrence within the weakest link, and

- **Rope:**

  It is the work release mechanism timing within the weakest link. In other words it is the pull scheduling signal that is used by the constraint to order the upstream processes to either produce faster, to slow down, or to stop.

Goldrat has accounted the resistance to changing as the major constraint to improvement. Pegels et al (2005) and Mabin et al (2001) have mentioned that the main task of implementing the theory of constraints (TOC) is answering some essential questions:

1- Constraint identification:

(What to change? Or Where the constraints within the system?). Identify the constraints means identify problems that prevent and limit achieving the system objectives, and determine the priority of these problems. Identifying which problem should be solved first based on the whole system performance.

Mainly, there are two types of constraints:

a) Physical constraints: all the sources (manpower, machines, or materials) are accounted as physical constraints, and

b) Policy constraints: production methods and processing procedures such as production scheduling and purchasing policy are examples of policy constraints.

2- Constraint exploitation:

(What to change to? Or What action should be taken regarding the constraints?). Decide How to Exploit the Constraint within the system. This question will be answered through identifying the main aim and objectives of the whole system, i.e. changes and solution selection process should be made in the light of the overall system task.

3- Subordination of other processes to the constraint:

(How to cause change? Or How the change is implemented?): Modify Everything Else, the overall system performance will be enhanced through adjustment and setting of non-constraints system components which allows the constraint component to maximise its performance. i.e. problems will be solved through implementing change and adjustment within the non-constraints components.

4- Elevate the system constraints:

(Whether the constraint (problem) is solved or not?): The overall system should be elevated and examined in order to determine whether the problems are solved or not.

5- **Go back to step one:**

(Any new constraints?): Once the problem was solved and the selected constraint was eliminated successfully, the circle should be repeated by going back to step one to identify new constraint (Gupta et al, 2004).

3.5.6- Six Sigma:

In 1998 Motorola implemented Six Sigma as quality measuring methodology. Six Sigma is the stand for a statistical unit which is used to measure the standard deviation of a population (Coronado et al, 2002). The six sigma is used to reduce production variation and defects wastes (Raisinghani et al, 2005).

The six Sigma strategy aims to:

1- **Achieve customer satisfaction:**

In global competitive environment, customer satisfaction becomes a key factor for any successful organisation. Survey and questionnaires are used to measure the satisfaction of the customer in order to investigate whether services and products supplied by the organisation meet customer expectation or not (Behara et al, 1995). The customer values are key element for any organisation aiming to take advantages over other competitors (Henderson et al, 2000).

2- **Quality improvement:**

Improve the quality through achieving zero defects, and reduce levels of scrap rework and rejected parts by setting appropriate tolerances on dimensions and parameters of the process (Linderman et al, 2003)

3- Process optimisation:

Optimise the process in order to improve productivity and profitability of the system (Lee-Mortimer, 2006). According to Antony et al (2005), and Goh et al (2004) that the Six-Sigma uses (DMAIC) methodology to solve the problem and improve the overall performance. The DMAIC methodology includes five steps such as:

a) **Define:** fully clear definition of customer values and organisation aims and objectives leads to precisely definition of problems that preclude achieving these aims and objectives (Kwak et al, 2006),

b) **Measure:** identifying base measurements is a vital task in order to determine any variation from designed state. Required data should be collected from many sources using valid manner to determine problems and metrics within the system (Schroeder et al, 2008),

c) **Analysis:** the collected data and process mapping of the current state should be analysed in order to determine root causes of the variation and opportunity for improvement (Hoerl, 2004),

d) **Improve:** In order to correct the variation and solve problems within the system; series processes of identifying, evaluating, selecting, and implementing of the right decision should be carried out based on the data analysis step (Bañuelas et al, 2004), and

e) **Control:** results should be evaluated and assessed to ensure that any cause of the problems has been removed and any variations from the designed state were corrected (Wiklund et al, 2002).

In summary Womack et al (2003) have stressed the fundamental role of lean tools within the organisational improvement process; however the book neglected the interconnection between these tools and the benefits of applying a complementary framework rather than using isolated tool. Numerous researchers have recognised and discussed the important of adopting complementary strategy which consists of synergistic approaches in order to be survived in the nowadays competitive environments. For example Venkatesh et al, (2007) have highlighted that the use of TQM will support and aid in achieving JIT system through reduction of process variations and rework-time which provide certain quality levels that result in minimising of inventories levels. On the other hand the use of the JIT technique will improve the process feedback and quality through problem identification. According to Venkatesh et al, (2007) organisations can benefit from applying an integrated framework which consists of JIT, TQM, TOC, and TMP instead of using a single technique. Gondhalekar et al (1995) have concluded that accomplishment of successful TQM system only can be achieved through the continuous improvement process, i.e. any organisation aiming to achieve a successful TQM system needs to co- implement Kaizen system because the Kaizen strategy provides a solid foundation in which the TQM culture can be built.

Arnheiter et al, (2005) have emphasised that the organisations will capitalise on the strength of both six sigma and lean philosophy (LSS), where each technique gives priority to certain aspects of the organisational performance. Therefore lean and Six Sigma integrated program (LSS) should be used systemically, where the sum of successful application of the parts is likely to be far less than the successful application of the whole.

Therefore lean needs to be reviewed as an integrated framework rather than selection of techniques, tools, or state of mind. Lean philosophy is complementary systemic learning approach which aims at helping organisations to build their internal business structure through improving the production line efficiency and performance, and eliminating all waste types and non-value added activities.

3.6- Barriers to implement lean:

Changing an organisation from old habits into new working system is difficult. Many organisations have failed attempts in lean transformation due to a variety of reasons. These reasons can be identified as barriers and roadblocks which may halt the conversion process into lean; therefore it is essential to address barriers that impede the organisation to adopt lean philosophy. Barriers to lean implementation vary from a firm to another one based on aims and objectives, and firm types. Swamidess (2000) has grouped theses barriers into four categories only.

1- **Technological barriers:**

   Technologies innovations have greatest impacts on the changing process. For example software, network, and internets technologies are fundamental factors within information and communications systems. Technology includes production design and scheduling, and quality and operation measurements. Updated technologies help organisations to close the gap from the current state to future (desired) state. On the other hand traditional and old technologies can impede lean implementation process.

2- Financial barriers:

Achanga et al (2006) have emphasised the vital role of the financial capacity within the process of lean implementation. The application of lean philosophy requires financial resources to cover the implementation expenses such as hiring change agent, and training the people. Organisations with limited financial resources may view the changing process as unnecessary loss of resources.

Lean manufacturing aims to develop integrated improvement strategy in order to achieve the top level organisation aims and objectives. For example lean implementation results in a reduction of WIP and inventories aiming to increase the materials flow through the system; in contrast traditional accounting views inventories reduction as reduction in the income. The traditional financial measures emphasise on sub-optimisation strategy which aims at improving a certain part or activity of the value stream in isolation of the whole system. The traditional financial measurements are inadequate because of:

a) They do not recognise the necessitate of a comprehensive integrated strategy to improve the whole system instead of controlling and improving a certain areas or activities in isolation, and

b) they provide unrealistic historical information and data (Maskell et al, 2007, Bititci, 2004).

3- External barriers:

Numerous external factors can influence and impede any lean transforming process. For example Hallgren et al (2009) and Devan (2004) have mentioned that the absence or insufficient of integrated communication and cooperation between the firms and their suppliers can prevent the changing process. According to Comm et al, (2000) misunderstanding of customer value is counted as a main factor which may prevent lean implementation process. Tax laws, competitive instant, trade agreements, and political and economical environments have direct influences on the transmutation process. For example the recent global economic recession situation causes sharp downturn in market demands which has a negative impact on any improvement process (Murray, 2009).

4- Internal barriers:

Narang (2008) and Brown et al (2006) have emphasised that the lean is not just a tool kit which is used to reduce the costs and inventories, or about removing wastes and enhancing productivity. Nevertheless Lean is about human resources, leadership, management, and culture. Achanga et al (2006) have mentioned the vital role of the commitments of managers and leaders in determining the success of lean implementation. An absence of strong supportive leadership to lean transformation will halt and block any transforming process. The beneficial lean journey starts with fully understanding of the lean principles and tools, and identifying the right technique for a specific sequence. Any misconception of lean concepts will result in failure of lean implementation. The internal barriers can be divided into three main factors such as:

a) Human factor:

The human natural tends to resist change; people resist the change and they are more comfortable with the existing working manner. A negative feeling may be developed when the lean is introduced within the organisation because of communication lack, and misconceive the real purpose of lean. Any non-cooperative and unsupportive attitude can easily obstruct the lean implementation (Kessler 2006, and Baker 2002),

b) culture factor:

Organisational culture: there are numerous definitions of the organisation culture. The culture can be defined as the behaviours, attitudes, and beliefs that exist within the organisation. The simplest description of the culture is the combination of processes, systems, symbols, and ritual that are adopted in order to achieve the organisation objectives and missions. The organisational culture is reflected in the structure way, how information is communicated, and the set up of hierarchal levels of the organisation (Longman et al, 2004). Based on works of Sim et al, (2009), Rashid et al, (2004), and Derek (2000) organisational culture is the most challengeable roadblock to lean implementation. Wilson (2001) has declared that the organisational culture is not monolithic because of the various sub-cultures existence which is accounted as a main source of conflict within the firm. The sub-culture can be existed as result of variation in individual skills and education, and departmental objectives and values. Organisations differ in their resistance and response to change based on some factors such as: degree of readiness to change within the organisation, leadership type, motivation and communication systems, individual knowledge and skill levels, and self-esteem and perspective. The accomplished revealing of any misunderstanding and fully analysing of the resistance forces within the organisation are the first step of a successful lean implementation, and

c) learning factor:

It has been mentioned in (3.3) that each lean implementation project is unique because organisations vary in terms of their aims, objectives, capabilities and skills, policies, culture, problems, and constraints. Lean transformation may fail, when a firm attempts to copy a lean project which has been implemented successfully by a competitor. The learning barrier is formed when the organisation cannot recognise that the lean implementation process is a continuous learning process rather than kit of tools and techniques.

3.7- Summary:

The lean philosophy is originally associated with the automobile sector and amazing results have been achieved through implementing the lean thinking approaches within the discrete manufacturing industries. The research here will attempt to demonstrate that the lean philosophy is not only limited to the discrete industries but all organisations can benefit from implementing lean thinking approaches within their systems aiming to minimise all non-value added activities. The research will attempt to convey the message to decision makers that the continuous manufacturing industry can be changed into lean organisation. The cement industry will be the representative of the continuous manufacturing industry within this study.

Chapter 4: Experimental design

Introduction:

The main aim of the current research is to develop a proposed standard method by which the lean manufacturing can be implemented successfully within the cement production line. The work here aims to convey massage to decision makers that the cement industry can benefit from implementing lean manufacturing. In order to attain these aims, some objectives should be achieved first. These objectives can be listed as:

1- Collect and verify the required data that needed to build-up a simulation model representing cement factory. The simulation model will give a visual image of the cement production line, highlight the value and non value activities, and help in decision making process which improves the line efficiency.

2- Identify variables and factors, which one has a great influence or effect on the efficiency of the production line.

3- An attempt to improve and enhance the performance parameters through eliminating or reducing wastes within the cement production line.

4- In order to achieve (1) and (2) , it is very important to identify cement production line performance parameters which yield an immediate positive feedback

5- Uses the Taguchi array to help in improvement of the cement industry efficiency.

Therefore, this chapter discusses and presents a detailed description of the method that developed to be research methodology for this undertaken study. The research design will be outlined with a particular emphasis on data collection and data generation processes that assist at achieving the above aims and objectives.

4.1- Overview of research methods:

According to Creswell (2009), and Yin (2003) the research methods can be classified onto three distinguished methods Quantitative, Qualitative, and Triangulation strategies:

4.1.1- Quantitative research:

According to William et al (2006), and Bertrand et al (2002) quantitative research involves numerical representation and statistical analysis for examining and determining the truthful of a hypothesis or theory within specific domain. Quantitative research studies and analyses the casual relationships between the variables within the process. This means the variables and their interrelationships are the main core of the quantitative research. Quantitative research focuses on objective rather than subjective. Quantitative research aims at:

1- Studying and examining the collected data to identify the problems based on given hypotheses or theory.

2- Using of a statistical technique to measure and analyse the relationships among the collected data.

3- Displaying the findings and results in form of tables and charts.

Robson (2006) has mentioned that there are mainly three types of quantitative research such as:

a) Experimental technique; random sample is subjected to experiment's conditions in order to examine and study the hypothesis or theory validly and verification,

b) Quasi-experiment technique; it is similar to experimental technique; however a specific sample is chosen to be examined and studied rather than random sample.

c) Survey technique; the required data and information are collected by means of using questionnaires or interviews techniques. Survey technique is widely used in social and longitudinal studies.

4.1.2- Qualitative research:

Qualitative research provides detailed descriptions of situations, procedures, problems and observed behaviours and general opinions. Mainly, the qualitative methodology focuses on subjective rather than objective (Graneheim et al, 2004).

There are two types of Qualitative research such as:

1- Exploratory research:

It helps in clarifying unclear defined problem and studying of unknown sector. Exploratory research mainly is based on secondary research as reviewing available historical data, literature, or case and pilot studies in order to orient the researcher with the research topic. The exploratory research aims to resolve the limitation of knowledge about the research topic through giving a clear and precise description of the problem, and

2- **Attitudinal research:**

It is subjective manure which is used to evaluate, understand, and examine a person or group of people opinions and beliefs toward specific object through deeply analysing of the collected data. It is mainly used in marketing researches.

According to Hines et al (1997) any success qualitative research should comply with specific procedures such as:

a) Collecting required data through one of:

i. Interviews, including three types:

- Structured interview, by using of tightly structured schedule of questions,
- Semi-structured interview, by using an open-ended questions, and
- Unstructured interview, by using unplanned discussion about the research's topic.

ii. focus groups, selecting and assembling a group of individuals to discuss the research's topic from personal side view,

iii. direct observation, this technique is used when the other techniques are unable to collect the required data,

iv. case study, it is used to have a hand on all details and gain in-depth understanding of the chosen sample case instead of the whole population. The case is chosen on base that it will represent the whole population, and

v. action research, the researcher participates in the process under the study.

b) Deeply describing of the situations, processes, people, and interactions and observed behaviours, and

c) Studying and examining the collected data to identifying the problems within restricted sample.

4.1.3- Triangulation:

Mangan et al, (2004) have mentioned that a combination of the quantitative and qualitative techniques will produce third type of research methods; which known as triangulation research method. Triangulation research examines and studies the research topic using more than one research method. This combination method enhances validation and verification of the collected data and hypnotises, where weaknesses of one approach can be compensated by strengths of another.

Mainly four types of triangulation research strategy such as:

1- Multiple methods:

Applying techniques of the both research techniques in the same undertaken research,

2- Multiple investigates:

Participating of more than researcher in the same undertaken project,

3- Multiple data sets:

Collecting and gathering the required data through variety sources and times, and

4- Multiple theories:

Testing and conforming number of theories and hypotheses in one research (Khalfan 2004).

Scandura et al (2000) have highlighted the main objectives of this strategy as:

a) Improving the reliability and validity of data and the research outcomes, and

b) using of a variety methods to study the research topic from more than one standpoint.

4.2- Design of Experiments (DOE):

Jacquez, (1998) emphasised the essential need for a structured purposeful approach which has the ability to consider all the involved variables and factors in a minimal number of experiments.

By the 1920s when designed experiments have become into their own, the statistical analysis of experimental results was very difficult. Consequently, data collection was designed to simplify calculations and the experiment is designed around minimising the work involved in data collection. In the 1940s Taguchi has developed vital improvement to the fundamentals of Design of Experiment (DOE) strategy which help in:

1- It is widely applied to identify the effective set of simulation model runs,

2- It is a faster analysis tool which can be implemented in order to explore optimisation and enhancement opportunities within the candidate firm.

According to Antony et al, (2006) the use of Taguchi Orthogonal Arrays helps in saving time, sources efficient, and cost effective through minimising the number of experiments to analysing large variety of key factors. Selection process of an appropriate Taguchi Orthogonal Array is controlled by number and levels of the variables within the process to be examined. Furthermore the chosen Orthogonal Array should be greater than or equal to the variables number; therefore the factorial design of the selected orthogonal array will be as (i^n) (Antony et al, 2004).

Where

i= variable levels, and

n= number of the variables.

Antony et al (2001 and 2004), and Tsai et al (1996) have mentioned the basic phases in applying Taguchi experimental design technique, these phases can be summarised as:

1- **Planning phase:**

It is a process of brainstorming to identify problems, objectives or the main purposes of carrying out the experiments, and main factors that influence the results

Where

a) factors are chosen according to their association with the problem or the main objective of the experiments and

b) levels are chosen according to the depth of the investigation needed to meet the objective or identifying which factor affect or the main cause of the problem.

2- **Conducting phase:**

It is running of the experiments according to the different combination of the factors and levels. The research here has integrated the Taguchi array with the simulation model. Therefore the simulation will run with the numbers of experiments according to the chosen array and response variable will be filled at the end of each run.

3- **Analysing phase:**

Identify which factor has the greatest effect on the response variable

4- **Confirming phase:**

Verification and validation of the results in order to check whether the problem is solved and optimal performance is achieved through new setting of the parameters.

In Summary, the benefit of using DOE is the ability to analyse the effect or “response” of many factors and levels with a minimum amount of experimentation. Factors are the independent variables that are expected to affect the response whereas levels are the quantitative or qualitative settings which will be tested. However, according to Thomas (2005), Simpson et al (2001 and 1997) there are some pitfalls and criticisms reported with the application of the Taguchi Orthogonal Array. On one hand Orthogonal Array is an useful approach to investigate the interrelationships between the variables and performance parameters; however it does not provide any visibility of the interdependently among the variables themselves.

In addition Taguchi method can not identify the precise number of variables to be included within the Orthogonal Array; i.e. Taguchi method cannot decide which variables will be tested. Therefore the research here will implement cause-and-effect matrix and connectivity matrix respectively in order to investigate the relationships among the variables, and determine the variable numbers which will be included within the Orthogonal Array.

4.3- Research steps:

The success and validity of any research critically depends on selection process of the research method which is used to collect, analyse, and interpret data. The selection process of the suitable research method is controlled by research objectives, and availability and type of the required data (Anumba 2006). The undertaken research consists of six steps as:

❖ **<u>Step one:</u> Data collection.**

The primary task is to identify the required data that can help in understanding the process. Once the right sources and accuracy levels of the data have been determined; identifying the method by which the required data will be collected becomes the next task. This exploratory undertaken research implements mixed method of both quantitative and qualitative data including:

1- Review of published literature for example works of (Bahatty et al 2004 Kizilaslan et al 2003, Hills et al 2002, and Bond et al 2000) have discussed the role of raw materials properties on the product quality, cement production line productivity, and reliability of the machineries. The research identified different factors that are associated or play an important role in the effectiveness of the cement production line.

2- Visits were arranged for data collection of the cement production line process from two selected sites:

- Ketton cement factory, Stamford, United Kingdom which hold 60% of the of the UK market share, and
- Suq-Alkhamis cement factory, Tripoli/Libya; which considered the largest cement plant in Libya.

3- Interviews were made with production line operators, coaches and production manager of both of factors. The obtained data were used to develop the simulation modelling elements and validate the obtained results.

The following data is required in order to determine different properties associated with every working area.

a) Cycle time of each working area,

b) capacity for each buffer or storage area,

c) batch size or number of repetitions/ month for each working area,

d) the actual operating time for each working area,

e) % rework at every working area,

f) % scrap associated with each working area,

g) number of breakdowns per month,

h) Mean Time To Repair (MTTR) for each working area, i.e. the time period which has been taken for the working area to be stopped (Khalil 2004), and

i) Mean Time To Failure (MTTF) for each working area, i.e. the frequency of stoppages of the equipment or breakdowns causing production stop.

The research will only use the Ketton factory process in developing simulation models; while the collected data from the both sites which represent two different organisational cultures is used to validate the research aspects and findings.

- **<u>Step two</u>: Developing of Simulation model.**

The main purpose of developing the model is to understand the process. Simul8 package is selected as an experimental testing tool for converting the cement production line into a simulation model. The main purpose of developing the model is to be able to highlight the value and non value activities that may occur within the cement production line and hence affect the efficiency. The model will include the following working areas:

a) Raw milling working area, which includes raw materials store, mill feed building, raw milling workstation, and raw meal silo.

b) Thermo-chemical working area, which includes the kiln system and clinker storage area, and

c) Cement grinding working area, which includes finish grinding workstation, packing house, and cement silos.

The simulation model is based on the following:

- Run time: The simulation model will run for 43200 minutes (which equivalents to one month)**.**
- Shift: The plant works on non-stop base, i.e. 24 hours per day.
- Results collection period: The results will be collected after 43200 minutes, which equivalents to one month.
- Schedule maintenance: The factory is planned to schedule maintenance stoppage for six weeks per year, i.e. the Actual Available Time for the three working areas is 46 weeks per a year.
- Types of products: No variety of products, i.e. only one type of Portland is produced.
- Probability distribution: Triangular distribution was chosen to be the probability distribution type within the undertaken research. According to Khalil et al (2008) the triangular distribution provides an acceptable trade-off between accuracy results. Khalil (2005) has categorised triangle distribution in three levels. For example as there is no standard cycle time, the research here uses the triangle distribution for the cycle time and it is identified as:
    - *a*, which mainly the most likely to be minimum cycle time,
    - *b* , is most likely the right time , and
    - *t*, is most likely the maximum time.

- <u>Step three:</u> **Identification of the interrelationships between the different variables.**

The research has identified several variables and factors, which control and govern the cement production line as identified in (2.2). According to the literature reviews and interviews there was a need to investigate the interrelationship between these factors. Therefore, Cause-Effect matrix was used to determine the interconnections and relationships between the variables i.e. non-relations, indirect-relations, and direct-relations as identified in tables (4.1- 4.3). The main technique which used to determine the variables is:

  - **Brainstorming technique:**

    It is a process of to identify problems, different factors that influence the efficiency of the cement production line, and it determines the measurement method of the process. In order to achieve the aim of the brainstorming sessions, preparation stage has been made by connecting the production people in the both sites informing them about the topic (identifying the main variables that associated within each working area, the interrelationships, and effects of the variables on the process performance. During the brainstorming sessions many creative ideas have been generated, and finally list of the most effective variables, the interrelationships, and their effects has been agreed through evaluation process of the all ideas.

RawMilling Process Varaibles	Air Flow Rate (cm³/min)	Temperature (C°)	Pressure (Psi)	Material Grindability	Material moisture (% of weight)	Material Bed Depth (cm)	Particles Size	Product Fineness (cm³/gr)	Recirculation Rate (% of feed materials)	Roller Number	Roller Radius (cm)	Mill Table Diameter (cm)	separator Speed (rpm)
Air Flow Rate (cm³/min)													
Temperature (C°)													
Pressure (Psi)													
Material Grindability													
Material moisture (% of weight)													
Material Bed Depth (cm)													
Particles Size													
Product Fineness (cm³/gr)													
Recirculation Rate (% of feed materials)													
Roller Number													
Roller Radius (cm)													
Mill Table Diameter (cm)													
separator Speed (rpm)													

Table (4.1): Raw Milling Process Cause andEffect matrix,

hermo-Chemical Process Variabl	PrimaryAir Flow Rate (cm^3/min)	Secondary Air Flow Rate (cm^3/min)	Fresh Air Flow Rate (cm^3/min)	Temperature (C°)	Flame Characteristics	Pressure (psi)	Volatile Concentration	Material Burnability	Material Flow Rate (cm^3/min)	Scrap Rate (%)	kiln Speed (rpm)	Residence Time in Kiln (min)	Cooler speed (rpm)	Cyclones Number
Primary Air Flow Rate (cm^3/min)														
Secondary Air Flow Rate (cm^3/min)														
Fresh Air Flow Rate (cm^3/min)														
Temperature (C°)														
Flame Characteristics														
Pressure (Psi)														
Volatile Concentration														
Material Burnability														
Material Flow rate (cm^3/min)														
Scrap Rate (%)														
kiln Speed (rpm)														
Residence Time in Kiln (min)														
Cooler speed (rpm)														
Cyclones Number														

Table (4.2): Thermo-chemical Process Cause andEffect matrix,

Finish Grinding Process Variables	Air Flow Rate (cm³/min)	Temperature C°	Pressure (Psi)	Clinker Feed Rate (%of mill volume)	Clinker Grindability	Clinker Nodules Size	Product Fineness (cm³/gr)	Recirculation Rate (% of feed materials)	separator Speed (rpm)	Mill% Ball Charging	Mill Lenght, Diameter Ratio (L/D)	Mill speed (rpm)
Air Flow Rate (cm³/min)												
Temperature (C°)												
Pressure (Psi)												
Clinker Feed Rate (%of Mill Volume)												
Clinker Grindability												
clinker Nodules Size												
Product Fineness (cm³/gr)												
Recirculation Rate (% of feed materials)												
separator Speed (rpm)												
Mill% Ball Charging												
Mill Lenght, Diameter Ratio (L/D)												
Mill speed (rpm)												

Table (4.3): Finish Grinding Process Cause andEffect matrix,

- **<u>Step four:</u> Developing a connectivity matrix to minimise the number of variables.**

  It was difficult to carry out experiments including all variables that influence the performance of each process within the cement production line as identified (2.2). Therefore, a connectivity matrix was developed in order to identify the most critical and influential variables which will be used in the different simulation model experiments i.e. the Taguchi Orthogonal Array. Only the variables that have the highest score of direct- relationships will be presented in the Orthogonal Array for each working area, see tables (5.4-5.6).

- **<u>Step five:</u> Using Taguchi Orthogonal Array.**

  As it was recommended in (4.2) the L_{27} was selected to be the orthogonal array for this research. L_{27} is suitable for range of (3^2 - 3^{13}) cases. Tables (4.4-4.6) show the Orthogonal Array for the cement production line.

Air flow Rate (c^3m/min)	Recirculation Rate (%weight)	Material Moisture	Material Grind-ability	Material Bed Depth (cm)	product Fineness (cm^3/gr)	Separator Speed (rpm)
7100	0.15	12	Easy	4	3900	60
7100	0.15	12	Easy	5	3950	65
7100	0.15	12	Easy	6	4000	75
7100	0.2	16	Normal	4	3900	60
7100	0.2	16	Normal	5	3950	65
7100	0.2	16	Normal	6	4000	75
7100	0.25	20	Hard	4	3900	60
7100	0.25	20	Hard	5	3950	65
7100	0.25	20	Hard	6	4000	75
7200	0.15	16	Hard	4	3950	75
7200	0.15	16	Hard	5	4000	60
7200	0.15	16	Hard	6	3900	65
7200	0.2	20	Easy	4	3950	75
7200	0.2	20	Easy	5	4000	60
7200	0.2	20	Easy	6	3900	65
7200	0.25	12	Normal	4	3950	75
7200	0.25	12	Normal	5	4000	60
7200	0.25	12	Normal	6	3900	65
7300	0.15	20	Normal	4	4000	65
7300	0.15	20	Normal	5	3900	75
7300	0.15	20	Normal	6	3950	60
7300	0.2	12	hard	4	4000	65
7300	0.2	12	hard	5	3900	75
7300	0.2	12	hard	6	3950	60
7300	0.25	16	Easy	4	4000	65
7300	0.25	16	Easy	5	3900	75
7300	0.25	16	Easy	6	3950	60

Table (4.4): L27A-Raw Milling Process.

Air flow Rate (cm³/min)	Temperature (c°)	Flame Characteristics	Volatile Concentration	Material Burn-ability	Residence Time in the kiln (min/ton)	Cooler Speed (spm)
50	200	Poor	Low	Easy	0.4	10
50	200	Poor	Low	Medium	0.5	11
50	200	Poor	Low	Difficult	0.6	12
50	940	Accepted	Medium	Easy	0.4	10
50	940	Accepted	Medium	Medium	0.5	11
50	940	Accepted	Medium	Difficult	0.6	12
50	1450	Optimum	High	Easy	0.4	10
50	1450	Optimum	High	Medium	0.5	11
50	1450	Optimum	High	Difficult	0.6	12
145	200	Accepted	High	Easy	0.4	12
145	200	Accepted	High	Medium	0.5	10
145	200	Accepted	High	Difficult	0.6	11
145	940	Optimum	Low	Easy	0.4	12
145	940	Optimum	Low	Medium	0.5	10
145	940	Optimum	Low	Difficult	0.6	11
145	1450	Poor	Medium	Easy	0.4	12
145	1450	Poor	Medium	Medium	0.5	10
145	1450	Poor	Medium	Difficult	0.6	11
215	200	Optimum	Medium	Easy	0.4	11
215	200	Optimum	Medium	Medium	0.5	12
215	200	Optimum	Medium	Difficult	0.6	10
215	940	Poor	High	Easy	0.4	11
215	940	Poor	High	Medium	0.5	12
215	940	Poor	High	Difficult	0.6	10
215	1450	Accepted	Low	Easy	0.4	11
215	1450	Accepted	Low	Medium	0.5	12
215	1450	Accepted	Low	Difficult	0.6	10

Table (4.5):L27A-Thermo-Chemical Process.

Clinker Grind-ability	Clinker Feed Rate (%of Mill Volume)	Product Fineness (Cm^2/g)	Mill%Ball Charging	Mill (L/D)	Mill speed %of critical speed	Separator speed (rpm)
Easy	20	3000	25	2	70	60
Easy	20	3000	25	3	80	70
Easy	20	3000	25	4	85	80
Easy	25	3500	30	2	70	60
Easy	25	3500	30	3	80	70
Easy	25	3500	30	4	85	80
Easy	30	4000	35	2	70	60
Easy	30	4000	35	3	80	70
Easy	30	4000	35	4	85	80
Normal	20	3500	35	2	80	80
Normal	20	3500	35	3	85	60
Normal	20	3500	35	4	70	70
Normal	25	4000	25	2	80	80
Normal	25	4000	25	3	85	60
Normal	25	4000	25	4	70	70
Normal	30	3000	30	2	80	80
Normal	30	3000	30	3	85	60
Normal	30	3000	30	4	70	70
Hard	20	4000	30	2	85	70
Hard	20	4000	30	3	70	80
Hard	20	4000	30	4	80	60
Hard	25	3000	35	2	85	70
Hard	25	3000	35	3	70	80
Hard	25	3000	35	4	80	60
Hard	30	3500	25	2	85	70
Hard	30	3500	25	3	70	80
Hard	30	3500	25	4	80	60

Table (4.6): L27A-Finish Grinding Process.

❖ **<u>Step six:</u> Performance measurements identification.**

As it has been mentioned at (3.3) that success lean changing journey must identify the right performance measures which give immediate positive feedback. Performance measurement is a tool which can inform whether the system in right path to achieve the objectives or not. Three parameters have been chosen to be the performance measures for the cement industry; these parameters are:

1- Cycle Times:

Based on the work of (Browning, 1998) the cycle time is one of the most essential elements within any organisation. Any reduction of the cycle time contributes to improve the frame overall by increasing customer satisfaction, reducing production costs, and providing key competitive advantages. The reduction of the cycle time can be obtained by eliminating or minimising all kinds of wastes and non-value added activities within the given system (Jones et al, 1999),

2- Equipment Utilization:

Machine utilisation can be defined as the amount of time which is spent on productive activities versus the available time for the machine to perform a work. Therefore, eliminate or minimise system wastes is essential element in order to increase the equipments utilisation (Jambekar, 2000). Lee et al (1994) have identified the equipment utilisation as:

$$\%\ Utilisation = \left(\frac{Available\ Time - Unused\ Time}{Available\ Time}\right) * 100$$

Where

$Available\ Time = Monthly\ Available\ Time(MAT)\ (43200\text{min}),$

$Unused\ Time = PMT + BT,$

$BT = Breakdown\ Time\ (\text{min}).$

$PMT = Planned\ Maintenance\ Time\ (min),$

Therefore the percentage of machine utilisation can be determined as:

$$\%Machine\ Utilisation = \left(\frac{MAT-(PMT+BT)}{MAT}\right) * 100 \quad (1)$$

3- Throughput rate per a working area:

The throughput is the amount of product that a machine can produce in a given time period. It is usually used as a basic determinant of the equipment efficiency (Braiden et al, 1996). Based on Little's law that

$$TH = \left(\frac{WIP}{CT}\right)(ton),$$

Where

$TH = Throughput\ (ton)$

$WIP = Work\ In\ Progress$, and

$CT = Cycle\ Time\ (\frac{min}{ton})$

However based on Hopp et al, (2001) that the WIP levels can be measured either in units of jobs or time. Therefore, the throughput is calculated as:

$$TH = \left(\frac{SRT - BT}{CT}\right)(ton) \quad (2)$$

$\underline{Where}$

$SRT = Scheduled\ Running\ Time$ (min)

$BT = Breakdown\ Time$ (min).

$CT = Cycle\ Time\ (\frac{min}{ton})$

The above equations (1 and 2) will be used to determine and calculate the values of the machine utilisation and throughput as it can be seen in tables (5.7-5.15).

These parameters are chosen because any improvement and enhancement within these three parameters give an immediate positive feedback which is easily to be recognised and reflected on the whole process aspects. Reduction of the cycle time and improvement of the throughput and machine utilisation can be translated into increased customer satisfaction and the overall performance (Lynes et al, 1994). According to Chung et al, (2005) the existing of strong and clear interrelationships between these three measures highlight the need of a comprehensive improvement method.

Chapter 5: Experimental Results

Introduction:

This chapter demonstrates the obtained results from implementing the experimental methodology which has been developed in chapter 4 in order to implement lean within the cement industry. The cement industry can become lean through identifying, and eliminating or minimising all types of wastes such as: high levels of inventories and WIP, and blocking and waiting times. The main objectives of this research are: maximising the throughput to satisfy the market demand, and identifying and minimising the cycle and breakdown times. These objectives are obtained through implementing the research methodology steps.

5.1- Results of the research Steps:

- <u>**Step one:**</u> **Data collection.**

  As it has been mentioned in (4.3.1) the undertaken research has used mixed method of the both quantitative and qualitative techniques in order to collect the required data. The collected data has been utilised to develop the simulation model of the cement factory and to validate the obtained results.

  1- Raw Milling process:

  a) The designed production rate = $250\left(\frac{ton}{h}\right)$

  b) Scheduled Running Time $= 80\%\ of\ the$ Actual Available Time ,

$$= 0.8 * 38880 = 31104 \frac{min}{month}$$

c) designed cycle time $= 0.5 \frac{min}{ton}$,

d) % rework (% recalculated) $= 15 - 25\%\ of\ the\ raw\ feed\ meal,$

e) % scrape $\approx 0\%,$

f) inventory and WIP capacities $= 80{,}000 ton\ and\ 20{,}000 ton$

$for\ the\ raw\ materials\ store\ and\ raw\ meal\ silo\ respectively$

g) number of breakdowns $= 4 - 6\ times\ per\ month$

$= 480 - 1800\ min\ per\ month$

h) Mean Time To Repair the breakdowns

(MTTR)$= 12 - 300\ minutes\ each.$

i) Mean Time To Failure (MTTF)

$= 4850 - 7608\ min$

2- Thermo-Chemical process:

a) The designed production rate $= 41 \frac{ton}{h},$

b) Scheduled Running Time

$= 90\%\ of\ the\ Actual\ Available\ Time$

$= 0.9 * 38880 = 34992 \frac{min}{month}$,

c) designed cycle time $= 1.4 \frac{min}{ton}$

d) % rework (% recalculated) $= 0\% \; of \; the \; feed \; meal$,

e) % scrape = 0.5%,

f) Clinker store capacity $= 100{,}000 \; ton$,

g) Mean Time To Repair the breakdowns

(MTTR) $= 300 - 480 \; minutes \; each.$

h) number of breakdowns

$= 6 - 8 \; times \; per \; month = 1800 - 3840 \; \text{min} \; per \; month$

i. Mean Time To Failure (MTTF)

$= 3867 - 5496 \; min$

3- Finish Grinding process:

a) The designed production rate= $= 133 \frac{ton}{h}$

b) Scheduled Running Time

$= 70\% \; of \; the \; working \; time \; available$

$= 0.7 * 38880 = 27216 \frac{min}{month}$

c) designed cycle time $\cong 0.5\frac{min}{ton}$,

d) % rework (% recalculated)

$= 10 - 20\%\ of\ the\ feed\ clinker,$

e) % scrape $\approx 0\%,$

f) Cement silos capacity$= 400{,}000\ ton.$

g) Mean Time To Repair the breakdowns (MTTR)

$= 400 - 600\,\text{min}\ per\ month$

h) number of breakdowns

$= 6 - 9\ times\ per\ month = 4088 - 5400\,\text{min}\ per\ month$

i. Mean Time To Failure (MTTF)

$= 2405 - 3826\,\text{min}\ per\ month$

❖ **<u>Step two</u> Developing of Simulation model:**

As it is mentioned in (2.1.4) that the most modern cement factories adopt the dry cement production system; therefore the dry production system is the core of this research.

The elements modelling of the cement factory consists of three main working areas such as:

1- Dry milling working area:

Based on the literature review the dry working area is composed of:

a) Mill feed building where the raw materials are blended forming a homogeneous raw meal before conveying to the vertical roller mill,

b) Vertical roller mill; the raw meal will be milled under the revolving rollers pulverising forces,

c) Separator; the fine particles are separated using the separator which located at the top of the mill unit, and

d) Product collector; the fine powder of the raw materials are swept up to the product collector using high stream of air, refer to figure (2.3).

2- Thermo-Chemical working area:

As it was mentioned in the figure (2.4) the dry thermo-chemical working area consists of:

a) Preheater tower, where process of heat transfer between the fed meal and the kiln exhausted gases takes place. The purpose of this process is to preheat the fed meal and partially hydro-carbonate the fed meal before reaching the kiln,

b) Precalciner, where the fed meal is completely decarbonised,

c) The kiln; the final structure of clinker nodules are formed when the fed meal reached the peak temperature at the burning zone, and

d) Cooler; high stream of fresh air is supplied aiming at cooling down the clinker which is discharged from the kiln lower end.

3- Finish Grinding working area:

As it was demonstrated in (2.1.5) the finish Grinding working area consists of:

a) Feed system is composed of bins, weight-feeders, and belt conveyors. The purpose of the feed system is to provide the right quantity of the clinker to the ball mill unit,

b) Ball mill; the cement powder will be obtained from the collision between the clinker nodules and the steel balls in the horizontal cylindrical drum,

c) Elevator; bucket elevator is used to convey the mill discharge to the separator, and

d) Separator; 3rd generation of the high efficiency separator is used to convey the fine cement powder to the electro-filter precipitator, then to the cement silos, refer to figure (2.5).

❖ **<u>Step three:</u> Identifying interrelationships between variables.**

Subsequent to the determination of variables and factors that control each process within the cement production line; all interrelationships types between these variables were identified using the cause and effect matrix

Tables (5.1-5.3) illustrate the interrelationships between the identified variables. For example;

D1 = direct interrelationship,

D0 = indirect interrelationship, and

I = absence of any interrelationships between the variables.

RawMilling Process Varaibles	Air Flow Rate (cm^3/min)	Temperature (C^o)	Pressure (Psi)	Material Grindability	Material Moisture (% of weight)	Material Bed Depth (cm)	Particles Size	Product Fineness (cm^3/gr)	Recirculation Rate (% of feed materials)	Roller Number	Roller Radius (cm)	Mill Table Diameter (cm)	separator Speed (rpm)
Air Flow Rate (cm^3/min)		D1	D1	I	D1	D1	D0	D1	D1	I	I	I	D1
Temperature (C^o)	D1		I	D1	D1	I	I	I	I	I	I	I	I
Pressure (Psi)	D1	I		I	I	D1	I	I	I	I	I	I	D0
Material Grindability	I	D1	I		D1	D1	D1	D1	D1	I	I	I	I
Material moisture (% of weight)	D1	D1	I	D1		D1	I	I	I	I	I	D0	I
Material Bed Depth (cm)	D1	I	D1	D1	D1		D0	I	I	I	I	I	D1
Particles Size	D0	I	I	D1	I	D0		D0	D0	I	I	I	D0
Product Fineness (cm^3/gr)	D1	I	I	D1	I	D0	D0		D1	I	I	I	D1
Recirculation Rate (% of feed materials)	D1	I	I	D1	I	I	D0	D1		I	I	I	D1
Roller Number	I	I	I	I	I	I	I	I	I		D1	D1	I
Roller Radius (cm)	I	I	I	I	I	I	I	I	I	D1		D1	I
Mill Table Diameter (cm)	I	I	I	I	I	D0	I	I	I	D1	D1		I
separator Speed (rpm)	D1	I	D0	I	I	D1	D0	D1	D1	I	I	I	

Table (5.1): Raw Milling Process Cause andEffect matrix,

Thermo-Chemical Process Variables	PrimaryAir Flow Rate (cm^3/min)	Secondary Air Flow Rate (cm^3/min)	Fresh Air Flow Rate (cm^3/min)	Temperature (C°)	Flame Characteristics	Pressure (psi)	Volatile Concentration	Material Burn-ability	Material Flow Rate (cm^3/min)	Scrap Rate (%)	kiln Speed (rpm)	Residence Time in Kiln (min)	Cooler Speed (rpm)	Cyclones Number
Primary Air Flow Rate (cm^3/min)		D0	D0	D1	D1	D0	D1	D1	D0	D0	I	D1	I	I
Secondary Air Flow Rate (cm^3/min)	D0		D0	D1	D0	D0	D1	D1	D0	D0	I	I	D1	D0
Fresh Air Flow Rate (cm^3/min)	D0	D0		D1	D0	I	I	I	I	D0	I	I	D1	I
Temperature (C°)	D1	D1	D1		D1	I	D1	D1	I	D0	I	D1	D1	D0
Flame Characteristics	D1	D0	D0	D1		I	D1	I	D0	D1	I	D1	D1	D0
Pressure (Psi)	D0	D0	I	I	I		I	I	D1	I	I	I	I	D1
Volatile Concentration	D1	D1	I	D1	D1	I		I	D0	D0	I	D1	D1	I
Material Burnability	D1	D1	I	D1	I	I	I		D1	I	I	D1	I	I
Material Flow rate (cm^3/min)	D0	D0	I	I	D0	D1	D0	D1		D0	D0	D1	D0	D1
Scrap Rate (%)	D0	D0	D0	D0	D1	I	D0	I	D0		I	I	D0	I
kiln Speed (rpm)	I	I	I	I	I	I	I	I	D0	I		D1	D0	I
Residence Time in Kiln (min)	D1	I	I	D1	D1	I	D1	D1	D1	I	D1		D0	I
Cooler speed (rpm)	I	D1	D1	D1	D1	I	D1	I	D0	D0	D0	D0		I
Cyclones Number	I	D0	I	D0	D0	D1	I	I	D1	I	I	I	I	

Table (5.2): Thermo-Chemical Process Cause andEffect matrix,

Finish Grinding Process Variables	Air Flow Rate (cm^3/min)	Temperature (C^o)	Pressure (Psi)	Clinker Feed Rate (%of mill volume)	Clinker Grindability	Clinker Nodules Size	Product Fineness (cm^3/gr)	Recirculation Rate (% of feed materials)	Separator Speed (rpm)	Mill% Ball Charging	Mill Lenght, Diameter Ratio (L/D)	Mill Speed (rpm)
Air Flow Rate (cm^3/min)		D1	D0	D0	I	I	I	D0	D1	I	I	I
Temperature (C^o)	D1		I	I	I	I	I	I	I	I	I	I
Pressure (Psi)	D0	I		D1	I	I	I	I	I	I	I	I
Clinker Feed Rate (%of Mill Volume)	D0	I	D1		D0	D0	D0	D0	D0	D1	D1	D1
Clinker Grindability	I	I	I	D0		D0	D1	D0	D0	D1	I	D1
clinker Nodules Size	I	I	I	D0	D0		D0	I	I	I	I	I
Product Fineness (cm^3/gr)	I	I	I	D0	D1	D0		D1	D1	I	I	I
Recirculation Rate (% of feed materials)	D0	I	I	D0	D0	I	D1		D1	I	I	I
separator Speed (rpm)	D1	I	I	D0	D0	I	D1	D1		I	I	I
Mill% Ball Charging	I	I	I	D1	D1	I	I	I	I		D1	D1
Mill Lenght, Diameter Ratio (L/D)	I	I	I	D1	I	I	I	I	I	D1		D1
Mill speed (rpm)	I	I	I	D0	D1	I	I	I	I	D1	D1	

Table (5.3): Finish Grinding Process Cause andEffect matrix,

- **<u>Step four:</u> Develop a connectivity matrix.**

In order to minimise the variables list into manageable number; connectivity matrixes have been developed for each process. Only the direct relationships will be presented within the connectivity matrixes, tables (5.4-5.6).

RawMilling Process Varaibles	Air Flow Rate (cm^3/min)	Temperature (C°)	Pressure (Psi)	Material Grindability	Material Moisture (% of weight)	Material Bed Depth (cm)	Particles Size	Product Fineness (cm^2/gr)	Recirculation Rate (% of feed materials)	Roller Number	Roller Radius (cm)	Mill Table Diameter (cm)	separator Speed (rpm)	
Air Flow Rate (cm^3/min)		D1	D1		D1	D1		D1	D1				D1	7
Temperature (C°)	D1			D1	D1									3
Pressure (Psi)	D1					D1								2
Material Grindability		D1			D1	D1	D1	D1	D1					6
Material moisture (% of weight)	D1	D1		D1		D1								4
Material Bed Depth (cm)	D1		D1	D1	D1								D1	5
Particles Size				D1										1
Product Fineness (cm^2/gr)	D1			D1					D1				D1	4
Recirculation Rate (% of feed materials)	D1			D1				D1					D1	4
Roller Number											D1	D1		2
Roller Radius (cm)										D1		D1		2
Mill Table Diameter (cm)										D1	D1			2
separator Speed (rpm)	D1					D1		D1	D1					4
	7	3	2	6	4	5	1	4	4	2	2	2	4	

Table (5.4): Raw Milling Process Connectivity matrix,

Thermo-chemical Process Variables	PrimaryAir Flow Rate (cm^3/min)	Secondary Air Flow Rate (cm^3/min)	Fresh Air Flow Rate (cm^3/min)	Temperature (C°)	Flame Characteristics	Pressure (psi)	Volatile Concentration	Material Burn-ability	Material Flow Rate (cm^3/min)	Scrap Rate (%)	kiln Speed (rpm)	Residence Time in Kiln (min)	Cooler Speed (rpm)	Cyclones Number	
Primary Air Flow Rate (cm^3/min)				D1	D1		D1	D1				D1			5
Secondary Air Flow Rate (cm^3/min)				D1			D1	D1					D1		4
Fresh Air Flow Rate (cm^3/min)				D1									D1		2
Temperature (C°)	D1	D1	D1		D1		D1	D1				D1	D1		8
Flame Characteristics	D1			D1			D1			D1		D1	D1		6
Pressure (Psi)									D1					D1	2
Volatile Concentration	D1	D1		D1	D1							D1	D1		6
Material Burnability	D1	D1		D1					D1			D1			5
Material Flow rate (cm^3/min)						D1		D1				D1		D1	4
Scrap Rate (%)					D1										1
kiln Speed (rpm)												D1			1
Residence Time in Kiln (min)	D1			D1	D1		D1	D1	D1		D1				7
Cooler speed (rpm)		D1	D1	D1	D1		D1								5
Cyclones Number						D1			D1						2
	5	4	2	8	6	2	6	5	4	1	1	7	5	2	

Table (5.5): Thermo-Chemical Process Connectivity matrix,

Finish Grinding Process Variables	Air Flow Rate (cm^3/mn)	Temperature (C°)	Pressure (Psi)	Clinker Feed Rate (%of mill volume)	Clinker Grindablty	Product Fineness (cm^3/gr)	Recirculaton Rate (% of feed materals)	separator Speed (rpm)	Mill% Ball Charging	Mill Lenght, Diameter Ratio (L/D)	Mill speed (rpm)	
Air Flow Rate (cm^3/mn)		D1						D1				2
Temperature (C°)	D1											1
Pressure (Psi)				D1								1
Clinker Feed Rate (%of Mill Volume)			D1						D1	D1		3
Clinker Grindablty						D1			D1		D1	3
Product Fineness (cm^3/gr)					D1		D1	D1				3
Recirculaton Rate (% of feed materials)						D1		D1				2
separator Speed (rpm)	D1					D1	D1					3
Mill% Ball Charging				D1	D1					D1	D1	4
Mill Lenght, Diameter Ratio (L/D)				D1					D1		D1	3
Mill speed (rpm)					D1				D1	D1		3
	2	1	1	3	3	3	2	3	4	3	3	

Table (5.6): Finish Grinding Process Connectivity matrix, Tables (5.7-5.9) illustrate the variables and their levels which are associated with each process.

Raw milling Process Factors	Level1	Level2	Level3
Air Flow Rate	7100	7200	7300
Recirculation Rate % of feeding rate	15	20	25
Material Moisture % of weight	12	16	20
Material Grind-ability	Easy	Normal	Hard
Material Bed Depth (cm)	4	5	6
Product Fineness	3900	3950	4000
separator Speed (rpm)	60	65	75

Table (5.7): Raw Milling Process variable levels

Thermo-chemical Process Factors	**Level1**	**Level2**	**Level3**
Air Flow Rate	50	130	210
Temperature	200	800	1400
Flame Characteristics	poor	accepted	optimum
Material Burn-ability	easy	normal	difficult
Volatile Concentration	Low	Medium	High
Residence Time in the kiln (min/ton)	0.4	0.6	0.8
Cooler Speed (spm)	10	11	12

Table (5.8): Thermo-Chemical Process variable levels.

Finish Grinding Process Factors	**Level1**	**Level2**	**Level3**
Clinker Grind-ability	Easy	Medium	Hard
Clinker Feed Rate %of Mill volume	20	25	30
Air flow Rate (m3/h)	70	105	140
Mill% Ball Charging	25	30	35
Recirculation Rate% of feed rate	Low	Medium	High
Product Fineness (Cm^2/g)	3900	3950	4000
Separator speed (rpm)	60	70	80

Table (5.9): Finish Grinding Process variable levels.

❖ **<u>Step five:</u> Results of Taguchi Orthogonal Array.**

Initially tables (5.10-5.12) demonstrate the theoretical values of the throughput and %machine utilisation for the three processes within the cement production line. The throughput and %machine utilisation are calculated using the equations (1 and 2).

Air flow Rate (cm^3/min)	Recirculation Rate (% Feed meal)	Material Moisture (% weight)	Material Grind-ability	Material Bed Depth (cm)	product Fineness (cm^3/gr)	Separator Speed (rpm)	Cycle Time (min/ton)	Breakdown Time (min)	Theoretical Throughput (ton)	Theoretical % Machine Utilisation
7100	0.15	12	Easy	4	3900	60	0.2	480	153120	71
7100	0.15	12	Easy	5	3950	65	0.2	480	153120	71
7100	0.15	12	Easy	6	4000	75	0.2	1140	149820	69
7100	0.2	16	Normal	4	3900	60	0.2	1140	149820	69
7100	0.2	16	Normal	5	3950	65	0.5	1140	59928	69
7100	0.2	16	Normal	6	4000	75	0.8	1140	37455	69
7100	0.25	20	Hard	4	3900	60	0.8	1800	36630	68
7100	0.25	20	Hard	5	3950	65	0.8	1800	36630	68
7100	0.25	20	Hard	6	4000	75	0.8	1800	36630	68
7200	0.15	16	Hard	4	3950	75	0.5	1140	59928	69
7200	0.15	16	Hard	5	4000	60	0.8	1140	37455	69
7200	0.15	16	Hard	6	3900	65	0.8	1140	37455	69
7200	0.2	20	Easy	4	3950	75	0.5	1800	58608	68
7200	0.2	20	Easy	5	4000	60	0.8	1140	37455	69
7200	0.2	20	Easy	6	3900	65	0.8	1140	37455	69
7200	0.25	12	Normal	4	3950	75	0.8	1800	36630	68
7200	0.25	12	Normal	5	4000	60	0.8	1800	36630	68
7200	0.25	12	Normal	6	3900	65	0.8	1140	37455	69
7300	0.15	20	Normal	4	4000	65	0.8	1800	36630	68
7300	0.15	20	Normal	5	3900	75	0.8	1800	36630	68
7300	0.15	20	Normal	6	3950	60	0.8	1140	37455	69
7300	0.2	12	hard	4	4000	65	0.8	1800	36630	68
7300	0.2	12	hard	5	3900	75	0.8	1800	36630	68
7300	0.2	12	hard	6	3950	60	0.8	1800	36630	68
7300	0.25	16	Easy	4	4000	65	0.5	1140	59928	69
7300	0.25	16	Easy	5	3900	75	0.5	1140	59928	69
7300	0.25	16	Easy	6	3950	60	0.5	1140	59928	69

Table (5.10): Raw Milling Process Theoretical Throughput and %Machine utilisation

Air flow Rate (cm³/min)	Temperature (c°)	Flame Characteristics	Volatile Concentration	Material Burn-ability	Residence Time in the kiln (min/ton)	Cooler Speed (spm)	CycleTime (min/ton)	Breakdown Time (min)	Theoretical Throughput (ton)	Theoretical %Machine Utilisation
50	200	Poor	Low	Easy	0.4	10	1.8	2820	17873	74
50	200	Poor	Low	Medium	0.5	11	1.8	2820	17873	74
50	200	Poor	Low	Difficult	0.6	12	1.8	3840	17307	72
50	940	Accepted	Medium	Easy	0.4	10	1.6	2820	20108	74
50	940	Accepted	Medium	Medium	0.5	11	1.6	2820	20108	74
50	940	Accepted	Medium	Difficult	0.6	12	1.8	2820	17873	74
50	1450	Optimum	High	Easy	0.4	10	1.6	1800	20745	77
50	1450	Optimum	High	Medium	0.5	11	1.6	1800	20745	77
50	1450	Optimum	High	Difficult	0.6	12	1.8	2820	17873	74
145	200	Accepted	High	Easy	0.4	12	1.8	1800	18440	77
145	200	Accepted	High	Medium	0.5	10	1.8	1800	18440	77
145	200	Accepted	High	Difficult	0.6	11	1.8	2820	17873	74
145	940	Optimum	Low	Easy	0.4	12	1.4	1800	23709	77
145	940	Optimum	Low	Medium	0.5	10	1.4	1800	23709	77
145	940	Optimum	Low	Difficult	0.6	11	1.6	1800	20745	77
145	1450	Poor	Medium	Easy	0.4	12	1.8	2820	17873	74
145	1450	Poor	Medium	Medium	0.5	10	1.8	2820	17873	74
145	1450	Poor	Medium	Difficult	0.6	11	1.8	3840	17307	72
215	200	Optimum	Medium	Easy	0.4	11	1.4	2820	22980	74
215	200	Optimum	Medium	Medium	0.5	12	1.6	1800	20745	77
215	200	Optimum	Medium	Difficult	0.6	10	1.8	2820	17873	74
215	940	Poor	High	Easy	0.4	11	1.8	3840	17307	72
215	940	Poor	High	Medium	0.5	12	1.8	3840	17307	72
215	940	Poor	High	Difficult	0.6	10	1.8	3840	17307	72
215	1450	Accepted	Low	Easy	0.4	11	1.4	1800	23709	77
215	1450	Accepted	Low	Medium	0.5	12	1.4	1800	23709	77
215	1450	Accepted	Low	Difficult	0.6	10	1.4	1800	23709	77

Table (5.11): Thermo-Chemical Process Theoretical Throughput and %Machine utilisation.

Clinker Grind-ability	Clinker Feed Rate (%of Mill Volume)	Product Fineness (Cm²/g)	Mill% Ball Charging	Mill (L/D) Ratio	Mill speed (% of critical speed)	Separator speed (rpm)	Cycle Time (min/ton)	Breakdown Time (min)	Theoretical Throughput (ton)	Theoretical %Machine Utilisation
Easy	20	3000	25	2	70	60	0.5	4088	46076	53
Easy	20	3000	25	3	80	70	0.5	4088	46076	53
Easy	20	3000	25	4	85	80	0.5	4744	44764	52
Easy	25	3500	30	2	70	60	0.5	4088	46076	53
Easy	25	3500	30	3	80	70	0.7	4744	31974.28571	52
Easy	25	3500	30	4	85	80	0.7	4744	31974.28571	52
Easy	30	4000	35	2	70	60	0.7	4088	32911.42857	53
Easy	30	4000	35	3	80	70	0.7	4744	31974.28571	52
Easy	30	4000	35	4	85	80	0.7	4744	31974.28571	52
Normal	20	3500	35	2	80	80	0.7	4088	32911.42857	53
Normal	20	3500	35	3	85	60	0.7	4088	32911.42857	53
Normal	20	3500	35	4	70	70	0.7	4744	31974.28571	52
Normal	25	4000	25	2	80	80	0.7	4744	31974.28571	52
Normal	25	4000	25	3	85	60	0.7	5400	31037.14286	50
Normal	25	4000	25	4	70	70	0.9	5400	24140	50
Normal	30	3000	30	2	80	80	0.7	4744	31974.28571	52
Normal	30	3000	30	3	85	60	0.7	4744	31974.28571	52
Normal	30	3000	30	4	70	70	0.7	4744	31974.28571	52
Hard	20	4000	30	2	85	70	0.7	5400	31037.14286	50
Hard	20	4000	30	3	70	80	0.9	5400	24140	50
Hard	20	4000	30	4	80	60	0.9	5400	24140	50
Hard	25	3000	35	2	85	70	0.7	4744	31974.28571	52
Hard	25	3000	35	3	70	80	0.7	4744	31974.28571	52
Hard	25	3000	35	4	80	60	0.9	5400	24140	50
Hard	30	3500	25	2	85	70	0.7	5400	31037.14286	50
Hard	30	3500	25	3	70	80	0.9	5400	24140	50
Hard	30	3500	25	4	80	60	0.9	5400	24140	50

Table (5.12): Finish Grinding Process Theoretical Throughput and %Machine utilisation.

❖ **<u>Step six:</u> Performance measurements.**

In order to identify and examine the effect of the variables on the performance parameters (cycle time, equipment utilisation, and throughput) for each process, the experiments listed in tables (5.13- 5.15) were carried out. As it has been mentioned at (4.3.1) that the only variables carrying high scores (green colour grads) within each connectivity matrix will be presented in the Orthogonal Arrays; for example air flow rate, temperature, material grind-ability, material moisture, material bed depth, product fineness, recirculation rate, and separator speed are accounted as the most effective variables within the raw milling process and they will be included in the raw milling Orthogonal Array.

Air flow Rate (cm³/min)	Recirculation Rate (% Feed Meal)	Material Moisture (% weight)	Material Grind-ability	Material Bed Depth (cm)	product Fineness (cm³/gr)	Separator Speed (rpm)	%Waiting before WIP minimise	%Blocking before WIP minimise	%Working before WIP minimise	Cycle Time (Min/ton) before WIP minimise	Breakdown Time (min) before WIP minimise	Throughput (ton) before WIP minimise	%Machine Utilisation before WIP minimise
7100	0.15	12	Easy	4	3900	60	22	11	67	0.27	135	114700	67
7100	0.15	12	Easy	5	3950	65	21	11	68	0.25	127	121957	68
7100	0.15	12	Easy	6	4000	75	32	14	54	0.26	258	119558	54
7100	0.2	16	Normal	4	3900	60	36	12	52	0.27	266	115932	52
7100	0.2	16	Normal	5	3950	65	37	11	52	0.53	266	57966	52
7100	0.2	16	Normal	6	4000	75	28	12	60	0.82	274	37506	61
7100	0.25	20	Hard	4	3900	60	40	16	44	0.88	438	35007	45
7100	0.25	20	Hard	5	3950	65	40	15	45	0.95	447	32135	46
7100	0.25	20	Hard	6	4000	75	37	15	48	0.92	429	33415	49
7200	0.15	16	Hard	4	3950	75	28	13	59	0.57	246	53948	59
7200	0.15	16	Hard	5	4000	60	29	12	59	0.4	246	77145	59
7200	0.15	16	Hard	6	3900	65	37	13	50	0.82	252	37809	50
7200	0.2	20	Easy	4	3950	75	37	16	47	0.58	405	52929	48
7200	0.2	20	Easy	5	4000	60	36	16	48	0.88	274	34955	48
7200	0.2	20	Easy	6	3900	65	38	12	50	0.92	286	33571	50
7200	0.25	12	Normal	4	3950	75	40	15	45	0.94	438	32763	46
7200	0.25	12	Normal	5	4000	60	47	16	37	0.92	445	33398	38
7200	0.25	12	Normal	6	3900	65	40	15	45	0.94	294	32707	45
7300	0.15	20	Normal	4	4000	65	41	15	44	0.86	399	35787	45
7300	0.15	20	Normal	5	3900	75	40	16	44	0.85	393	36301	45
7300	0.15	20	Normal	6	3950	60	29	12	59	0.85	264	36197	60
7300	0.2	12	hard	4	4000	65	38	15	47	0.89	417	34326	48
7300	0.2	12	hard	5	3900	75	38	16	46	0.91	423	33864	47
7300	0.2	12	hard	6	3950	60	32	16	52	0.93	435	32977	53
7300	0.25	16	Easy	4	4000	65	35	14	51	0.61	286	50356	51
7300	0.25	16	Easy	5	3900	75	26	15	59	0.59	274	52432	60
7300	0.25	16	Easy	6	3950	60	24	18	58	0.30	282	102060	59

Table (5.13): Raw Milling Process OA before reducing WIP

Air flow Rate (cm^3/min)	Temperature (C^o)	Flame Characteristics	Volatile Concentration	Material Burn -ability	Residence Time in the kiln (min/ton)	Cooler Speed (spm)	%Waiting before WIP minimise	%Blocking before WIP minimise	%Working befor WIP minimise	Cycle Time (min/ton) before WIP minimise	Breakdown Time (min) before WIP minimise	Throughput (ton) before WIP minimise	% Machine Utilisation before WIP minimise
50	200	Poor	Low	Easy	0.4	10	30	14	56	2.3	449	15019	56
50	200	Poor	Low	Medium	0.5	11	29	14	57	2.4	488	14377	57
50	200	Poor	Low	Difficult	0.6	12	35	15	50	2.5	619	13749	50
50	940	Accepted	Medium	Easy	0.4	10	32	13	55	2.1	460	16444	55
50	940	Accepted	Medium	Medium	0.5	11	33	14	54	2	472	17260	54
50	940	Accepted	Medium	Difficult	0.6	12	28	11	60	2.4	476	14382	60
50	1450	Optimum	High	Easy	0.4	10	23	9	68	2.1	339	16501	68
50	1450	Optimum	High	Medium	0.5	11	20	9	70	2.2	342	15750	70
50	1450	Optimum	High	Difficult	0.6	12	10	14	67	2.6	449	13286	67
145	200	Accepted	High	Easy	0.4	12	28	11	60	2.6	348	13325	60
145	200	Accepted	High	Medium	0.5	10	34	12	54	2.4	336	14440	54
145	200	Accepted	High	Difficult	0.6	11	29	14	57	2.4	433	14400	57
145	940	Optimum	Low	Easy	0.4	12	35	15	50	1.9	327	18245	50
145	940	Optimum	Low	Medium	0.5	10	37	15	48	1.9	324	18246	48
145	940	Optimum	Low	Difficult	0.6	11	36	12	51	2.2	333	15754	51
145	1450	Poor	Medium	Easy	0.4	12	28	13	59	2.3	456	15016	59
145	1450	Poor	Medium	Medium	0.5	10	27	14	59	2.6	460	13282	59
145	1450	Poor	Medium	Difficult	0.6	11	37	15	48	2.6	566	13241	48
230	200	Optimum	Medium	Easy	0.4	11	39	15	46	1.9	321	18248	46
230	200	Optimum	Medium	Medium	0.5	12	38	15	47	2	324	17334	47
230	200	Optimum	Medium	Difficult	0.6	10	27	14	59	2.2	437	15707	59
230	940	Poor	High	Easy	0.4	11	34	14	51	2.1	547	16402	51
230	940	Poor	High	Medium	0.5	12	33	14	53	2.2	552	15683	53
230	940	Poor	High	Difficult	0.6	10	35	15	50	2.3	542	14978	50
230	1450	Accepted	Low	Easy	0.4	11	35	15	50	1.7	327	20391	50
230	1450	Accepted	Low	Medium	0.5	12	36	13	51	1.9	330	18243	51
230	1450	Accepted	Low	Difficult	0.6	10	33	14	53	1.9	333	18242	53

Table (5.14): Thermo-Chemical Process OA before reducing WIP

Clinker Grind-ability	Clinker Feed Rate (%of Mill Volume)	Product Fineness (Cm^2/g)	Mill%Ball Charging	Mill (L/D)	Mill speed (% of critical speed)	Separator speed (rpm)	%Waiting before WIP minimise	%Blocking before WIP minimise	%Working before WIP minimise	Cycle Time (min/ton) before WIP minimise	Breakdown Time before WIP minimise	Throughput (ton) before WIP minimise	%Mechine Utilisation before WIP minimise
Easy	20	3000	25	2	70	60	19	12	69	0.65	460	41025	69
Easy	20	3000	25	3	80	70	22	9	69	0.63	464	42321	69
Easy	20	3000	25	4	85	80	24	9	67	0.65	595	40817	67
Easy	25	3500	30	2	70	60	23	9	68	0.64	472	41647	68
Easy	25	3500	30	3	80	70	23	11	66	0.92	610	28822	66
Easy	25	3500	30	4	85	80	23	11	66	0.95	625	27896	66
Easy	30	4000	35	2	70	60	23	9	68	0.93	492	28639	68
Easy	30	4000	35	3	80	70	21	12	67	0.92	605	28827	67
Easy	30	4000	35	4	85	80	25	12	63	0.97	640	27305	63
Normal	20	3500	35	2	80	80	23	11	66	0.95	500	28027	66
Normal	20	3500	35	3	85	60	22	10	68	0.94	496	28330	68
Normal	20	3500	35	4	70	70	22	11	67	0.95	630	27891	67
Normal	25	4000	25	2	80	80	21	11	68	1	655	26471	68
Normal	25	4000	25	3	85	60	29	14	57	1	810	26316	57
Normal	25	4000	25	4	70	70	32	14	53	1.28	792	20573	53
Normal	30	3000	30	2	80	80	25	11	64	0.97	645	27300	64
Normal	30	3000	30	3	85	60	24	11	65	0.95	625	27896	65
Normal	30	3000	30	4	70	70	38	16	45	1	665	26461	45
Hard	20	4000	30	2	85	70	41	15	43	1	792	26334	43
Hard	20	4000	30	3	70	80	40	15	44	1.4	870	18754	44
Hard	20	4000	30	4	80	60	36	14	50	1.4	858	18763	50
Hard	25	3000	35	2	85	70	38	13	49	1	665	26461	49
Hard	25	3000	35	3	70	80	41	14	45	1	680	26446	45
Hard	25	3000	35	4	80	60	34	13	53	1.4	864	18759	53
Hard	30	3500	25	2	85	70	39	13	48	1	798	26328	48
Hard	30	3500	25	3	70	80	47	14	39	1.4	870	18754	39
Hard	30	3500	25	4	80	60	46	13	41	1.4	858	18763	41

Table (5.15): Finish Grinding Process OA before reducing WIP.

a) The literature review has shown that the cement industry is characterised by high levels of WIP and inventories. Many problems and root causes of performance insufficiencies can be shrouded and buried behind the WIP high levels. Therefore; the priority of implementing Lean within the cement industry is to eliminate or minimise the WIP and inventories levels. In addition; one of the research objectives is to determine and examine effects of WIP minimisation on the performance parameters. One of the main reasons of high WIP levels is the non-optimised batch size. Therefore, all workstations capacities have been reduced by10% in order to minimise the WIP levels. Tables (5.16- 5.18) illustrate the effects of WIP reduction on the system performance parameters.

Air flow Rate (cm³/min)	Recirculation Rate (% Feed Meal)	Material Moisture (% weight)	Material Grind-ability	Material Bed Depth (cm)	product Fineness (cm³/gr)	Separator Speed (rpm)	%Waiting after WIP minimise	%Blocking after WIP minimise	%Working after WIP minimise	Cycle Time (min/ton) after WIP minmise	Breakdown Time (min) after WIP minmise	Throughput (ton) after WIP minimise	%Machine Utilisation after WIP minimise
7100	0.15	12	Easy	4	3900	60	18	8	74	0.12	132	258100	74
7100	0.15	12	Easy	5	3950	65	17	8	75	0.16	125	188896	75
7100	0.15	12	Easy	6	4000	75	24	14	62	0.11	256	285630	62
7100	0.2	16	Normal	4	3900	60	27	12	61	0.12	262	265879	61
7100	0.2	16	Normal	5	3950	65	24	16	60	0.38	263	80736	60
7100	0.2	16	Normal	6	4000	75	15	18	67	0.67	271	45882	67
7100	0.25	20	Hard	4	3900	60	31	18	51	0.63	435	48992	51
7100	0.25	20	Hard	5	3950	65	30	17	53	0.77	444	39612	53
7100	0.25	20	Hard	6	4000	75	27	16	57	0.77	427	39944	57
7200	0.15	16	Hard	4	3950	75	21	13	66	0.22	243	139014	66
7200	0.15	16	Hard	5	4000	60	22	12	66	0.25	241	123452	66
7200	0.15	16	Hard	6	3900	65	23	14	63	0.64	250	48513	63
7200	0.2	20	Easy	4	3950	75	28	17	55	0.43	401	71402	55
7200	0.2	20	Easy	5	4000	60	32	11	57	0.70	270	43923	57
7200	0.2	20	Easy	6	3900	65	27	14	59	0.74	283	41763	59
7200	0.25	12	Normal	4	3950	75	31	17	52	0.76	433	40570	52
7200	0.25	12	Normal	5	4000	60	37	14	49	0.77	438	39930	49
7200	0.25	12	Normal	6	3900	65	25	22	53	0.69	387	44389	53
7300	0.15	20	Normal	4	4000	65	29	19	50	0.68	395	45294	50
7300	0.15	20	Normal	5	3900	75	28	20	52	0.70	289	44274	52
7300	0.15	20	Normal	6	3950	60	18	13	69	0.67	261	45897	69
7300	0.2	12	hard	4	4000	65	32	13	55	0.74	410	41255	55
7300	0.2	12	hard	5	3900	75	29	17	54	0.66	419	46776	54
7300	0.2	12	hard	6	3950	60	32	16	52	0.78	431	39324	52
7300	0.25	16	Easy	4	4000	65	26	15	59	0.46	282	66714	59
7300	0.25	16	Easy	5	3900	75	28	16	56	0.41	271	75571	56
7300	0.25	16	Easy	6	3950	60	28	14	58	0.15	279	202796	58

Table (5.16): Raw Milling Process OA after reducing WIP.

Air flow Rate (cm³/min)	Temperature (C°)	Flame Characteristics	Volatile Concentration	Material Burn -ability	Residence Time in the kiln (min/ton)	Cooler Speed (spm)	%Waiting after WIP minimise	%Blocking after WIP minimise	%Working after WIP minimise	Cycle Time (min/ton) after WIP minmise	Breakdown Time aftre WIP minmise	Throughput (ton) after WIP minimise	%Machine Utilisation after WIP minimise
50	200	Poor	Low	Easy	0.4	10	25	13	62	2.1	404	16470	62
50	200	Poor	Low	Medium	0.5	11	23	14	63	1.6	463	21581	63
50	200	Poor	Low	Difficult	0.6	12	28	13	59	2.3	594	14956	59
50	940	Accepted	Medium	Easy	0.4	10	27	12	61	1.9	415	18198	61
50	940	Accepted	Medium	Medium	0.5	11	24	16	60	1.8	427	19203	60
50	940	Accepted	Medium	Difficult	0.6	12	15	18	67	2.2	451	15700	67
50	1450	Optimum	High	Easy	0.4	10	10	15	75	1.9	294	18262	75
50	1450	Optimum	High	Medium	0.5	11	13	9	78	1.4	297	24782	78
50	1450	Optimum	High	Difficult	0.6	12	11	15	74	2.2	404	15722	74
145	200	Accepted	High	Easy	0.4	12	20	13	67	2.4	313	14450	67
145	200	Accepted	High	Medium	0.5	10	22	18	60	1.7	291	20412	60
145	200	Accepted	High	Difficult	0.6	11	23	14	63	2.3	398	15041	63
145	940	Optimum	Low	Easy	0.4	12	28	17	55	1.7	292	20412	55
145	940	Optimum	Low	Medium	0.5	10	25	22	53	1.1	299	31539	53
145	940	Optimum	Low	Difficult	0.6	11	27	16	57	1.9	298	18260	57
145	1450	Poor	Medium	Easy	0.4	12	25	15	65	2.1	411	16467	65
145	1450	Poor	Medium	Medium	0.5	10	18	16	66	1.8	425	19204	66
145	1450	Poor	Medium	Difficult	0.6	11	25	22	53	2.4	521	14363	53
230	200	Optimum	Medium	Easy	0.4	11	29	19	51	1.8	286	19281	51
230	200	Optimum	Medium	Medium	0.5	12	28	20	52	1.8	269	19291	52
230	200	Optimum	Medium	Difficult	0.6	10	19	15	66	1.4	392	24714	66
230	940	Poor	High	Easy	0.4	11	27	16	57	1.9	492	18158	57
230	940	Poor	High	Medium	0.5	12	25	14	59	2	517	17238	59
230	940	Poor	High	Difficult	0.6	10	31	13	55	2.1	487	16431	55
230	1450	Accepted	Low	Easy	0.4	11	30	16	55	0.9	272	38578	55
230	1450	Accepted	Low	Medium	0.5	12	25	18	57	1.1	275	31561	57
230	1450	Accepted	Low	Difficult	0.6	10	26	15	59	1.7	298	20408	59

Table (5.17): Thermo-Chemical Process OA after reducing WIP.

Clinker Grind-ability	Clinker Feed Rate (%of Mill Volume)	Product Fineness (Cm²/g)	Mill%Ball Charging	Mill (L/D) Ratio	Mill speed (% of critical speed)	Separator speed (rpm)	%Waiting after WIP minimise	%Blocking after WIP minimise	%Working after WIP minimise	Cycle Time (min/ton) after WIP	Breakdown Time (min) after WIP minmise	Throughput (ton) after WIP minmise	%Mechine Utilisation after WIP minimise
Easy	20	3000	25	2	70	60	14	8	78	0.29	435	92038	78
Easy	20	3000	25	3	80	70	16	7	77	0.51	409	52386	77
Easy	20	3000	25	4	85	80	17	9	74	0.48	540	55388	74
Easy	25	3500	30	2	70	60	16	8	76	0.49	417	54508	76
Easy	25	3500	30	3	80	70	16	11	73	0.8	585	33176	73
Easy	25	3500	30	4	85	80	16	11	73	0.8	570	33195	73
Easy	30	4000	35	2	70	60	17	7	76	0.76	437	35117	76
Easy	30	4000	35	3	80	70	16	7	75	0.8	530	33245	75
Easy	30	4000	35	4	85	80	17	8	72	0.72	585	36863	72
Normal	20	3500	35	2	80	80	16	11	73	0.8	445	33351	73
Normal	20	3500	35	3	85	60	15	8	76	0.82	421	32567	76
Normal	20	3500	35	4	70	70	16	9	74	0.83	595	31965	74
Normal	25	4000	25	2	80	80	17	8	75	0.65	630	40763	75
Normal	25	4000	25	3	85	60	34	11	55	0.85	755	31025	55
Normal	25	4000	25	4	70	70	29	19	52	1.18	717	22381	52
Normal	30	3000	30	2	80	80	18	11	71	0.63	590	42121	71
Normal	30	3000	30	3	85	60	17	11	72	0.83	570	31995	72
Normal	30	3000	30	4	70	70	21	11	68	0.66	630	40145	68
Hard	20	4000	30	2	85	70	31	16	53	0.82	717	32206	53
Hard	20	4000	30	3	70	80	32	17	51	1.3	785	20262	51
Hard	20	4000	30	4	80	60	28	20	52	1	833	26293	52
Hard	25	3000	35	2	85	70	32	13	55	0.83	610	31947	55
Hard	25	3000	35	3	70	80	29	17	54	0.68	635	38957	54
Hard	25	3000	35	4	80	60	31	16	53	1.25	839	21030	53
Hard	30	3500	25	2	85	70	26	15	59	0.81	763	32547	59
Hard	30	3500	25	3	70	80	31	16	53	1.29	845	20373	53
Hard	30	3500	25	4	80	60	29	14	57	1.23	823	21385	57

Table (5.18): Finish Grinding Process OA after reducing WIP.

Chapter 6: Discussion

Introduction:

The research aims to convey the message to the decision-maker that the lean philosophy is applicable to all organisations. The research has attempted to prove that the continuous process industry with specific focus on the cement industry can benefit from implementing lean philosophy.

Lean has been widely adopted and spread in discrete manufacturing industries; however the challenge nowadays is to implement the lean philosophy within process industries. Hitomi (1996) and Sheilh (2003) defined the process industry as process of mixing, separating, forming, or chemical reactions in order to add values to the input through either continuous or batch production modes based on variety and amount of the products. Continuous production mode is adopted with high volume/ low variety; while batch process industry is typically used as production mode to produce medium quantities of goods associated with medium variety. According to (Dennis et al 2000) process industry covers a wide variety of business such as: Pharmaceutical industry, oil refining, steel, glass, paper, and cement industry. This chapter attempts to discuss the obtained results and findings in the previous chapters.

6.1- Needs of Lean in the cement Industry:

Nowadays, the adopted production system within the cement industry is traditional mass production using single-purpose machines to produce very high volume of standardised products within long processing times. Large batch sizes and silos of finished goods and storerooms for WIP are accounted as another main criterion of the mass production system.

The cement industry is characterised by certain well-defined conditions such as:

1- High capital investments deter any new entrants, i.e. the high costs of building up a new cement factory inhibit other competitors from entering the business,

2- A large market share and absence of any substitutable materials, i.e. the high demand for the cement specially in the developing countries as Libya, and

3- The availability of cheap raw materials and energy motivates the cement industry to be one of the most successful sectors especially in the oil countries as Libya.

6.1.1- SWOT analysis of the cement industry:

The findings and desiccations in the preceding section have revealed that there are strengths, weaknesses, opportunities, and threats associated with the cement industry. In this section a SWOT analysis will be employed in order to identify the current state of the cement industry and highlight the need to change (Sauer, 1998).

Strength	Weaknesses
- Availability of cheap raw materials. - Availability of cheap fuels and energy in some of developing countries as Libya. - Need of the cement and absence of substitutes materials to replace the cement.	- High rates of unexpected breakdown and maintenance costs. - Un-standard operating process. - Transportation and freight costs. - Organisational culture.
Opportunities	**Threatens**
- Increase the domestic demands, and potential to export the cement. - Technological changes.	- Unstable and sudden changes in political rules and regulations. - Economical changes and competition environments.

Table (6.1): SWOT analysis of the cement industry

The SWOT analysis emphasises that the cement industry has the features to be successful industry, and there are number of changing-forces which drive the decision-maker to think about applying and implementing lean philosophy; these forces are:

1- **Fuel and energy prices:** the significant global increases of fuel and energy costs has heavily impacted the cement industry,

2- **Market pressure:** the undue pressure to keep prices lower than the competitors. Furthermore the high market demands put the cement industry under pressure to simultaneously reduce cycle time and downtimes, and increase utilisation and throughput of the equipments.

Based on the findings that the cement industry might be far away from implementing lean thinking approaches because awareness lacking about adoption of lean philosophy. Therefore it is essentially necessary to eliminate and minimise all kinds of non valued added activities within the cement industry in order to achieve customer satisfaction, product costs reduction, and overall performance improvement.

6.2- Barriers to Implement lean within Cement Industry:

On one hand the cement industry is motivated to be lean in order to increase the productivity and enhance the overall performance. On the other hand, there are numerous of roadblocks and barriers which may prevent the implementation of lean within the cement industry such as:

1- **Competition and motivation environment:**

   a) **Political rules and regulations:** The cement industry is protected by the government in some developing countries. For example many of cement factors in the developing countries are part of a large corporation firms or involved with government bodies and feel no need for any changing program (Al-Khalifa et al, 2000). For example the cement industry in Libya is state-owned sector.

   b) **Absence of customer voice and compotation:** No customer pressure drives or enforces the cement industry to initiate any improvement process. For example most of the Libyan cement industry stockpiles are traded and consumed within the domestic market where customers buy what found not what they expect (Al-Khalifa et al, 2000). Furthermore absence or low competition levels because of high market restrictions. This leads to misconception of no need to implement any kind of improvement strategies.

2- **Organisational culture:**

According to Galpin, (1996) substantial changes in the organisational culture are required for most organisations that seek to be a learning organisation. Based on Lawrence et al (1993) that the cultural barriers can be grouped into three categories such as:

a) **Employees participation obstacles:** according to Hokoma et al, (2010) that the people will reluctant to involve in any improvement process because of lack of knowledge, skills, and adequate training programs. Wong (1998) has emphasised that the lack of real understanding of the principles can be accounted as the main factor of unsuccessful improvement journey in the developing countries. Existing of miss-concepts of the lean philosophy especially in the third world organisations where the lean is viewed as a collection of tools which can be used to solve the temporary problems instead of new way of thinking.

b) **Management obstacles:** Hokoma et al (2008) have provided an insight the limitations of the management body within the Libyan cement industry towards the implementation of any improvement techniques. Furthermore the study has identified number of problems, attitudes, and issues that hamper any changing process. For example the absence of communications, management commitments, and unclear strategy towards continuous improvement are among the main factors that halt any changing process (Youssef, 2006).

c) **Resistance to change:** it is one of the most significant barriers to change within the cement industry where the people tend to continue operating as they have in past. In addition case of scepticism about any new ideas is typical attitude within the cement industry (Derobert et al, 1998).

As mentioned in (3.6) that the changing process is not easy task and it needs significant efforts for Generating and increasing of the lean awareness through the whole organisation levels in order to achieve the commitment and supports from the management, and people involvement. The critical factors within this stage are:

i. Motivation of the people: The main task of this stage is to motivate and empower the people within the organisation to identify the necessity for changing the current state in order to achieve the aims and objectives of the organisation. People neither motivated nor contributed to do their work more efficiently if they are uncertain about future state and worried about their positions. Therefore situation of fear needs to be driven out through establishing of open clear communication methods where the organisation missions, aims, and future state are communicated through the whole organisation levels.

ii. providing the right training and education programs: Good and appropriate training and education programs should be provided in order to build multifunctional teams, and handle the miss-concepts and encourage the people to participate in the changing and decision making processes.

6.3- Discussion of the research results:

Here in this section the research attempts to discuss the obtained results through answering some questions which provide detailed description of the proposed transition steps.

1- **Do the proposed steps have the ability to identify wastes and non-value added activities within the examined system?**

   - The proposed steps have started with process mapping of the cement industry in order to achieve a fully understanding of the cement production line, and to track unsought processes. The process mapping of the cement production line has identified some non-value added activities such as large batch sizes and high levels of WIP and inventories. Table (6.2) illustrates the wastes and non-value added activities which are associated with the cement industry.

Lean Wastes	The Cement production line wastes
Overproduction	Overproduction muda is presented obviously within the cement manufacturing process resulting in very high levels of WIP between sub-processes (Das, 1987).
Waiting	Different batch sizes are associated with the cement production line create waiting wastes which affect flow of materials. Furthermore the unplanned maintenance can be one of the main sources of waiting waste within the cement industry.
Motion	The workers travel long destinations between different workstations.
Transportation	Materials need to be transported for a long journey starting form quarry site to the cement silos. In addition the layout of the cement factory may cause transportation wastes.
Inventory	Cement industry is one of the industries with largest inventories and WIP. Un-standardisation and batch size verities can be among the causes of excessive inventories situation.
Over processing	Unnecessary long time is spent for milling the hard and large particles.
Defects	High levels of recirculation (rework) are associated with the both raw milling and finish grinding processes.

Table (6.2): wastes within the cement production.

2- **Do the proposed steps have the ability to identify the most effective and influence variables and factors within the examined system?**

❖ The second step was to identify variables and factors that control and govern the cement production line. The research has identified numerous number of variables are associated with each process through involvement of production people within the both sites, refer to (2.2).

3- **Do the proposed steps have the ability to identify the interrelationships between the variables?**

❖ The interrelationships between these variables were investigated and examined aiming to determine the most effective variables through applying Cause and Effect matrix. Tables (5.1-5.3) have illustrated all the types of the interdependently relationships between different variables that associated with each process. These interrelationships can be classified into three main categories such as: direct interrelationships, where situation of direct effects are existing between particular variables. For example there is direct relationship between the air flow rate and pressure inside the vertical roller mill in the raw milling process. Furthermore table (5.1) shows the indirect relationship between pressure inside the vertical roller mill and the separator speed. The indirect interrelationship is resulted from the direct relationship between the both pressure and separator speed with the air flow rate. Figures (5.2-5.36) demonstrate the most significant variables that control each process within the cement production line. For example the air flow rate, recirculation rate, material moisture, and material grind-ability are the most effectual variables within the raw milling process.

The results show that the values of cycle time, waiting and blocking percentages, and breakdown time within the raw milling process are proportional to:

- The increasing in the values of the air flow and recirculation rates.
- Percentages of moistures within raw materials.
- Grand-ability levels of raw materials.

In order to simplify the research task the number of the variables needed to be minimised into manageable list through applying the connectivity matrix for each process and the only variables with high score of direct interrelationships will be represented within the Orthogonal Arrays, i.e. the orthogonal array was chosen based on the outcomes of the Cause Effect and connectivity matrices, see tables (5.4-5.6).

4- Do the proposed steps have the ability to identify the any positive feedback within the system?

- As mentioned at (3.3) the successful lean journey should identify the most important performance measures which ensure immediate feedback and visible results. According to (4.3.1) that the cycle time, throughput, and machine utilisation have been chosen as the key performance parameters in order to identify positive feedbacks (improvement) within the cement production line, see tables (5.10- 5.15).

The next section will illustrate the reasons for not choosing the bottleneck and quality aspects among the performance parameters of the cement industry:

- The quality within the cement industry is controlled by physical and chemical properties of the three key materials (raw meal, feed meal, and clinker). The quality standards within the both raw milling and finish grinding processes are ensured by the characteristics stability of the raw materials and the clinker. For example online monitoring system is fitted within the cement production line in order to analyse and compare the standard deviation of materials with the target one. The online system provides a clear indication of whether any required correction actions to achieve the target standard deviations; furthermore the high levels of re-circulated materials within the both raw milling and finish grinding processes enhance the product quality, and eliminate or prevent any scrap percentages. However the high recirculation levels should be viewed as waste from lean philosophy perspective. The high recirculation rates reduce the productivity, and increase the cycle times and production costs. Based on the data at (5.1) has emphasised the absence or very low levels of defected units and scrap rates that associated with the cement production line. In addition the quality parameter is already embedded and a function within cycle time and throughput parameters; therefore the quality issues might be assumed as insignificant performance parameter.

- According to (Duwayri et al, 2006) the bottleneck is stated as the constraints which can be resulted from machine capacities and cycle times variations within the system. Lee et al (2004) have emphasised that the bottleneck machine makes the upstream workstations to be blocked and the downstream workstations to be starved; however as it has been mentioned at (3.2.2) the high inventories and WIP capacities may mask the influence of the bottleneck within the cement production line.

5- Do the proposed steps have the ability to examine and investigate the effects of the variables on the selected performance parameters, and validate the obtained results from different scenarios?

- As it has mentioned at (4.2) that the research here has proposed a design of improvement exercise method which combines the simulation modelling technique with proper Taguchi Orthogonal Array in order to examine the obtained results from the experiments, refer to (5.1). The simulation will run with a specific number of experiments according to the chosen array which will be updated at the end of each run. The Taguchi orthogonal array has been used to collect the results according to different scenarios in order to determine the effects and influences of the variables on the response variables (performance parameters). Tables (5.10-5.15) demonstrate the Orthogonal Arrays which illustrate the different scenarios where the selected variables can have an effect on the selected performance measurements.

The undertaken research has proven the vital impacts of variables and factors on the performance parameters. For example high throughput in the raw milling process will be obtained at low air flow and material recirculation rates, and low levels of moisture in combination of easy to grind properties. Furthermore the throughput and machine utilisation within the finish grinding process will be improved when appropriate flow rate of easy to grind clinker is fed into the tube grinding machine which has the right percentage of ball charges in order to produce cement with medium product fineness. The insufficient flow rate of hard grind-ability clinker, high product fineness, and incorrect ball charging percentage are the main causes of the high levels of waiting and blocking percentages, and long cycle and breaking times within the finish grinding process.

The WIP reduction has a great effect on the production line efficiency. Figures (6.1-6.4) illustrate comparison picture of variables and factors values before and after reducing the WIP within the raw milling process in order to demonstrate the enhancement that obtained within the raw milling process after reducing the WIP level. The throughput and machine utilisation are improved in combination with reduction of the cycle time, and breakdown time as a result of WIP reduction.

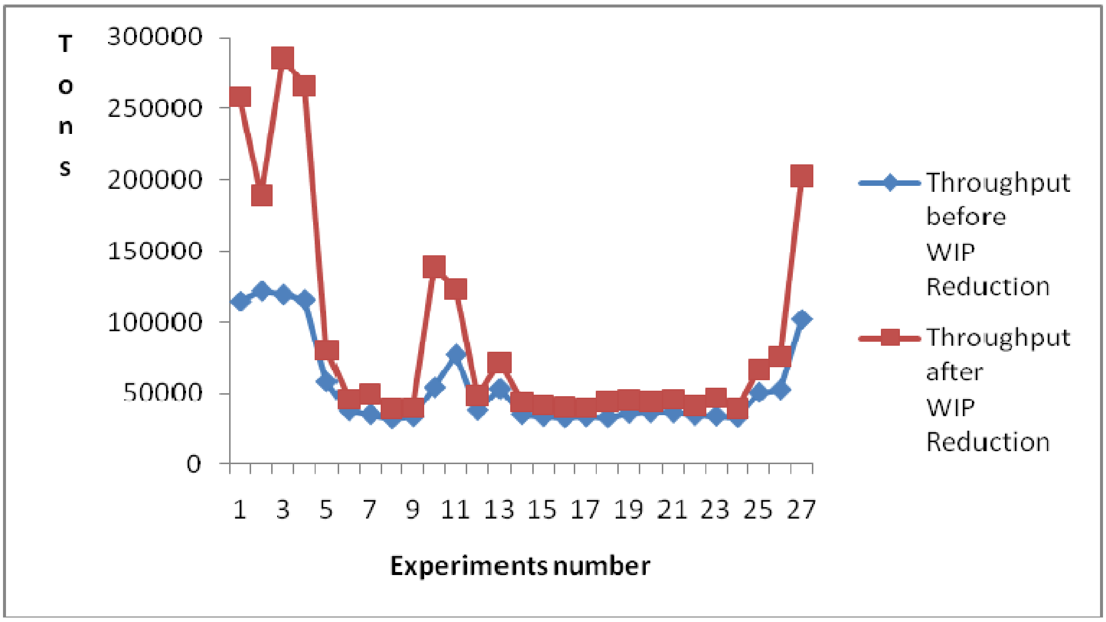

Figure (6.1): Throughput before and after WIP reduction.

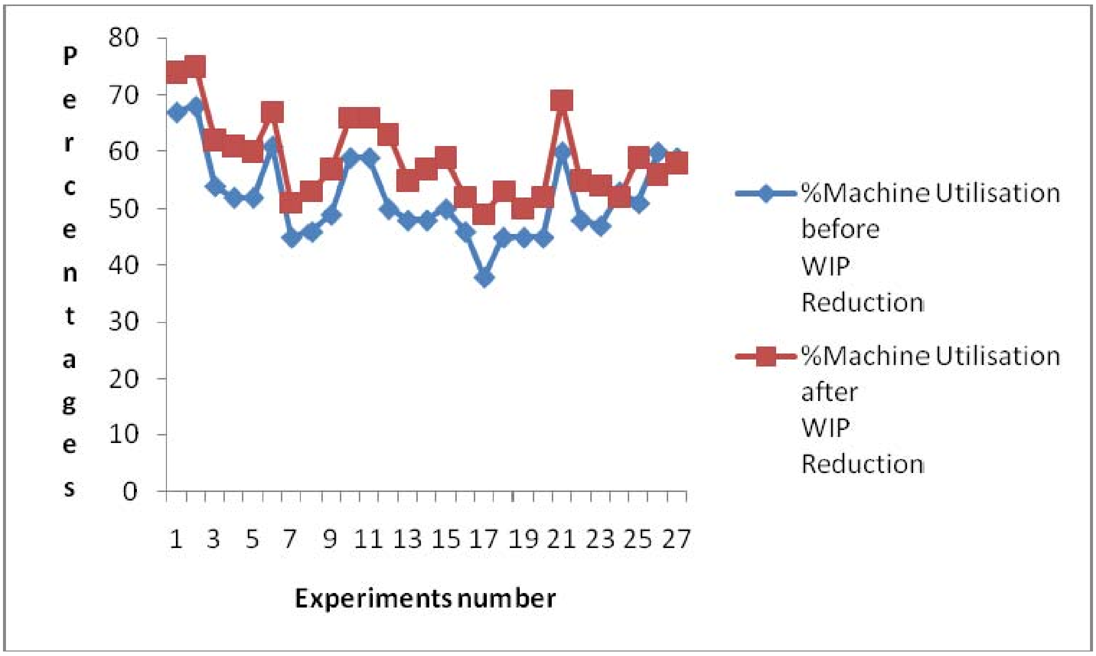

Figure (6.2): %Machine Utilisation before and after WIP reduction.

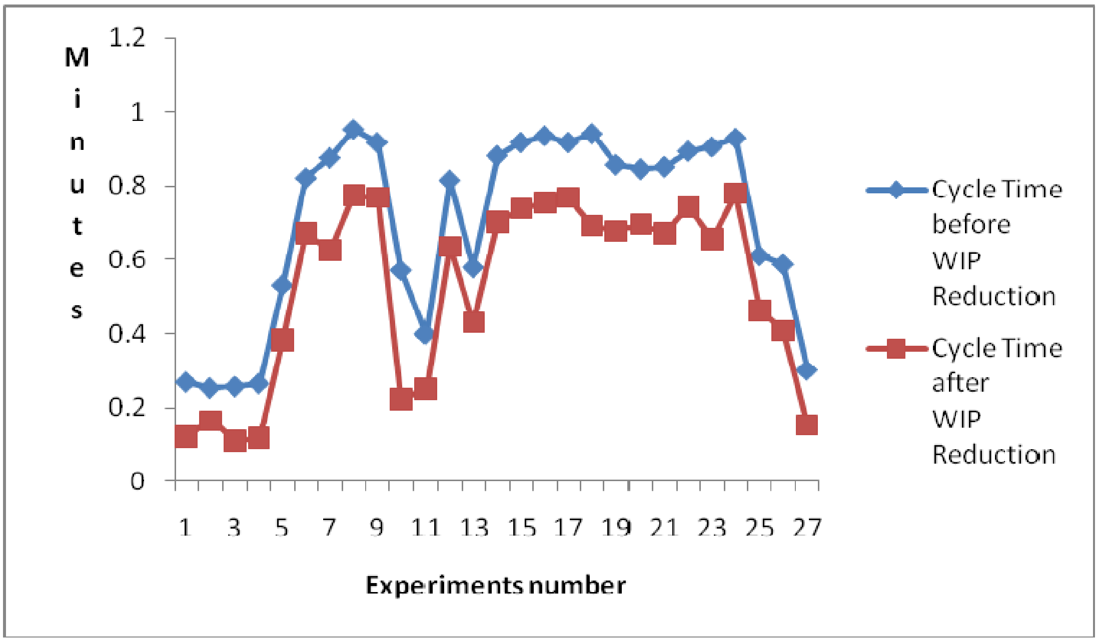

Figure (6.3): Cycle Time before and after WIP reduction.

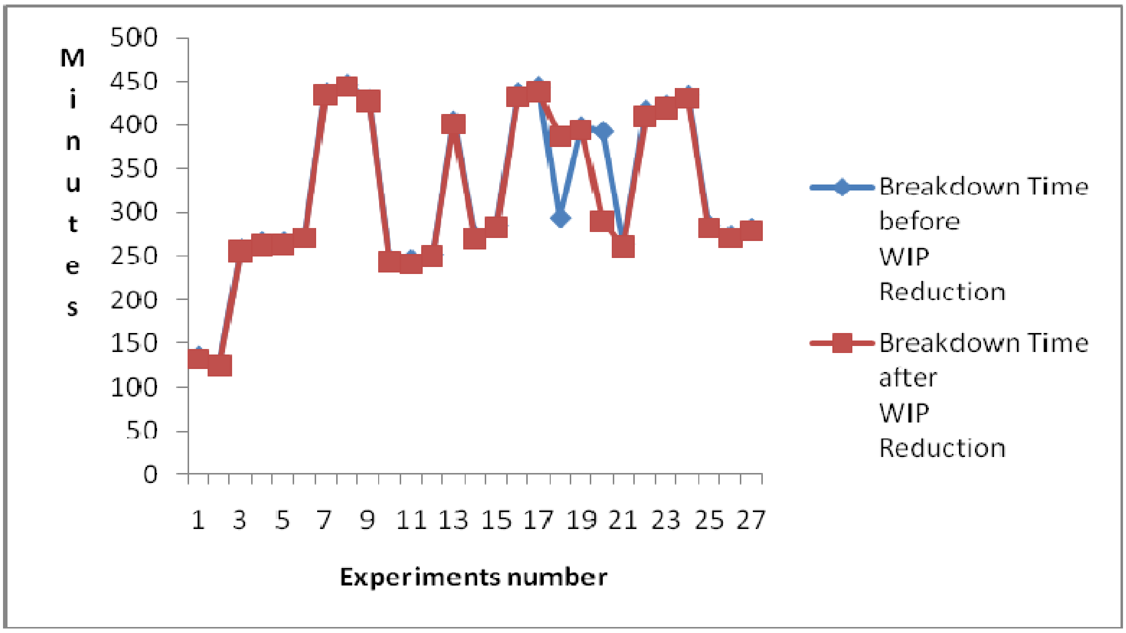

Figure (6.4): Breakdown Times before and after WIP reduction.

Chapter 7: Conclusion

In the today's uncertain global environments organisations of all sizes are enforced to look for an edge over their competitors, and to streamline their activities with a view to improving quality service and costs in order to survive in the difficult economic and trading environments. Many organisations have adopted successfully lean strategy to improve their productivity and efficiency.

The research has succeeded to convey the message to the decision-maker that the lean philosophy is not limited to specific organisations; however process industries and deffernt organisations can reward amazing results through adopting the lean thinking.

The research has used the cement industry which is accounted as the typical representative of the continuous process industry where the mass production system is adopted using inflexible and expensive machines to produce, transport, and accumulate tens of thousands of materials within each working area. The research has contributed to the body of the knowledge by studying and identifying the non-value added activities and attempted to implement lean within the cement industry. The cement industry is ideal example of the continuous process manufacturing; however the research has studied the cement industry through dividing the cement production line into three main processes such as raw milling process, thermo-chemical process, and finish grinding process. The research has handled each process as discrete or single process aiming to identify the interrelationships between the variables that associated with each process, and to determine the effects of these variables on the chosen performance parameters for each process. The research has highlighted some of the barriers that may cause the gap between the desired and the actual results, and prevent the cement industry from achieving any improvement. Based on the research findings the misconception and absence of open communication and commitments are among the most effective roadblocks within the cement industry. Furthermore the research has contributed to the knowledge through proposing standard steps which can be used as road map for implementing the lean philosophy within continuous industries and other organisations. The proposed transition steps are simple, direct, and understandable by the all people at the different organisation levels. The proposed transition steps have the answer to the possible questions and requests of the decision makers within the cement industry or other organisations. The proposed transition steps can be summarised as:

1- Achieving a fully understanding of the system through applying of the process mapping technique.

2- Identifying the main variables and factors that control the system.

3- Identifying different types of interrelationships between the variables and their effects on the performance parameters.

4- Validating the obtained results. The main novelty of the proposed steps was the combination of the simulation model with the Taguchi Orthogonal Array aiming to improve the cement production line's efficiency.

The cement industry has all the features to be very thriving sector through adopting lean thinking. The successful implementation of the lean strategy ensures the achievement of the maximum efficiency in combination of simultaneous reduction of lead time and production costs within the cement production line. The successful lean implementation will be achieved when:

- The right training and education program is provided to the people aiming to misconceptions about the lean philosophy.
- The right support and commitments of the management are obtained.
- The right motivation system is established.

Chapter 8: Future Work

This work was the first step to explore and study the opportunity for implementing of the lean thinking within the cement industry, and many other steps and approaches can be proposed aiming to enhance the cement industry efficiency. As it is often the case with each research where additional questions are raised and new opportunity of study are opened.

1- Based on the research findings there are number of wastes and non-value added activities associated with the cement industry such as over-production, over-processing, motion, materials transportation, and high levels of recirculation, refer to table (6.2). The suggested future works can be in area of and identifying and implementing the appropriate lean approach in order to solve each of these wastes; for example an attempt to implement the just in time approach within the cement industry can be as a proper research area aiming to resolve the problem of over-production. As it has been shown in the preceding chapters that the cement industry is characterised by very high breakdown levels; therefore a studying and identifying causes and how to eliminate or minimise these problems is accounted as good prospect for another future work. In summary there are good opportunities to address and study each non-value added activity that identified in table (6.2).

2- The research here has briefly mentioned the barriers and roadblocks that may prevent the improvement process within the cement industry; therefore a deep and intensive study and investigation of these barriers and their elimination methods could by recommended as opportunity for future work.

3- Furthermore the main focus of another future research should be in the area of empirical area through attempting to validate the proposed transition steps within different organisations.

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Appendix:

The next figures illustrate Taguchi analysis mechanism (Minitab) results. The results show the most significant variables within each process before and after reducing the WIP.

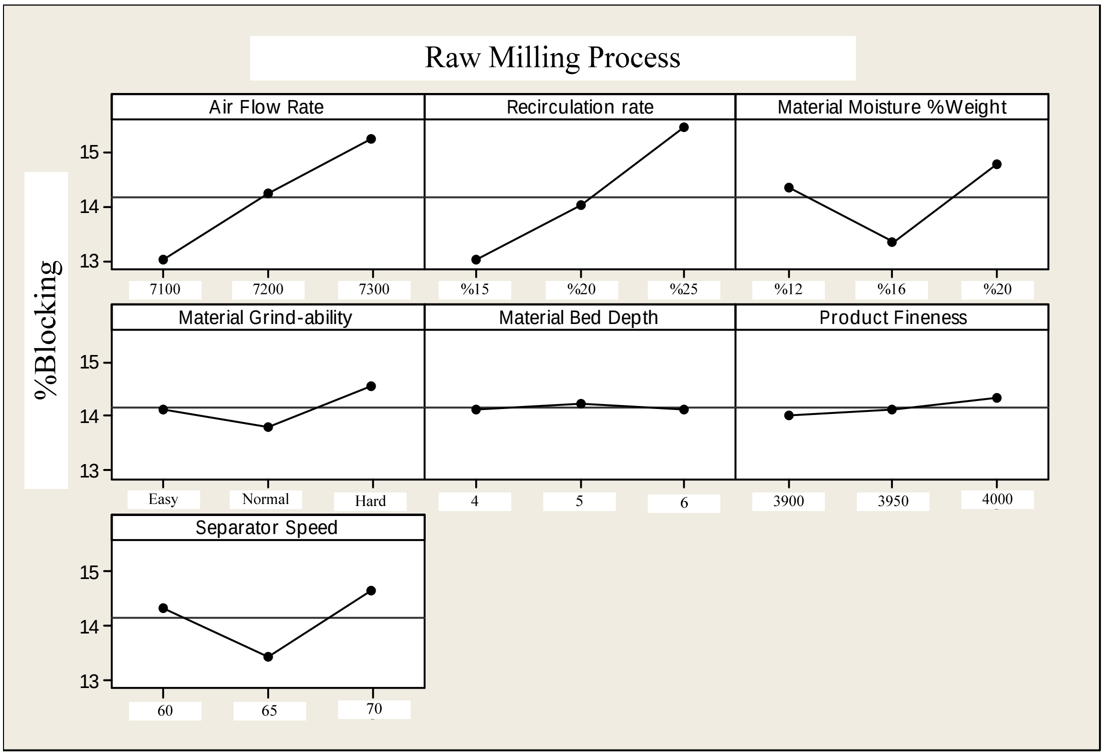

Figure (1): Raw Milling Process % Blocking before reducing the WIP.

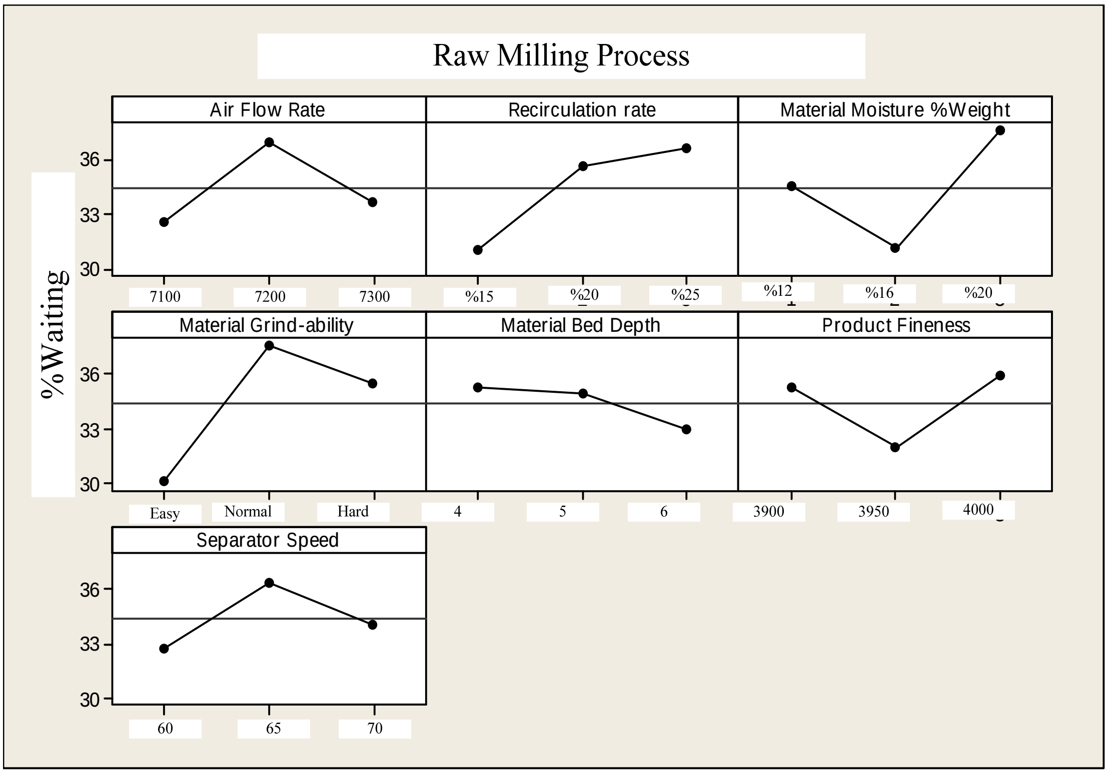

Figure (2): Raw Milling Process % Waiting before reducing the WIP.

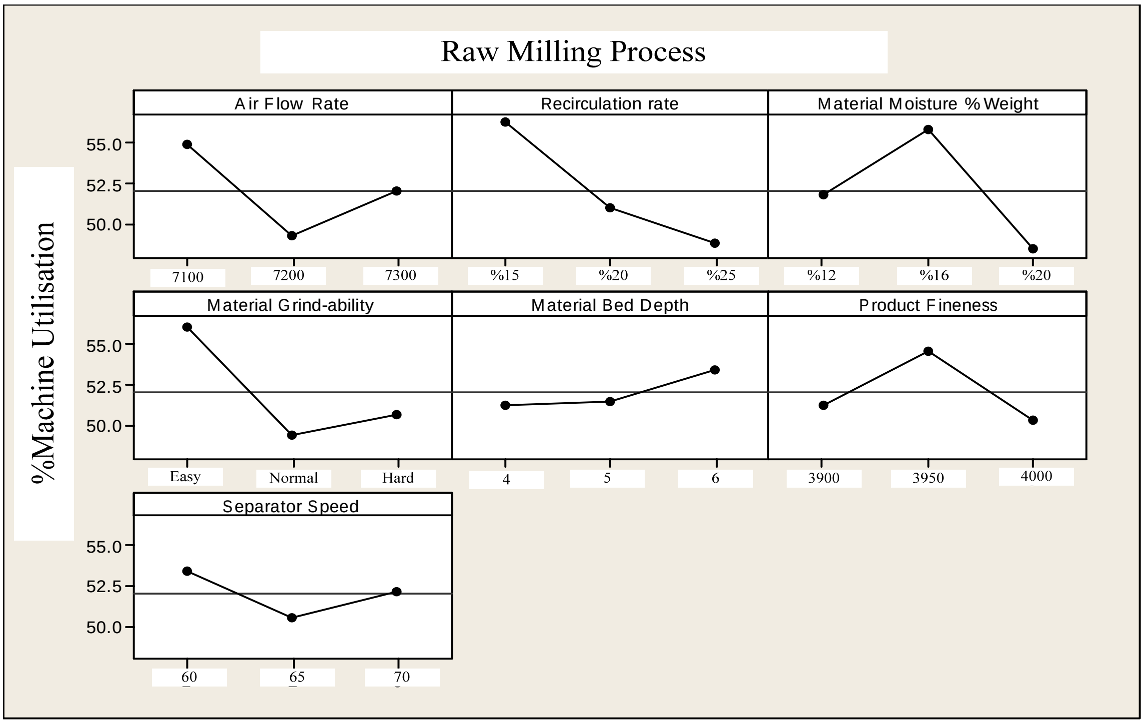

Figure (3): Raw Milling Process % Machine Utilisation before reducing the WIP.

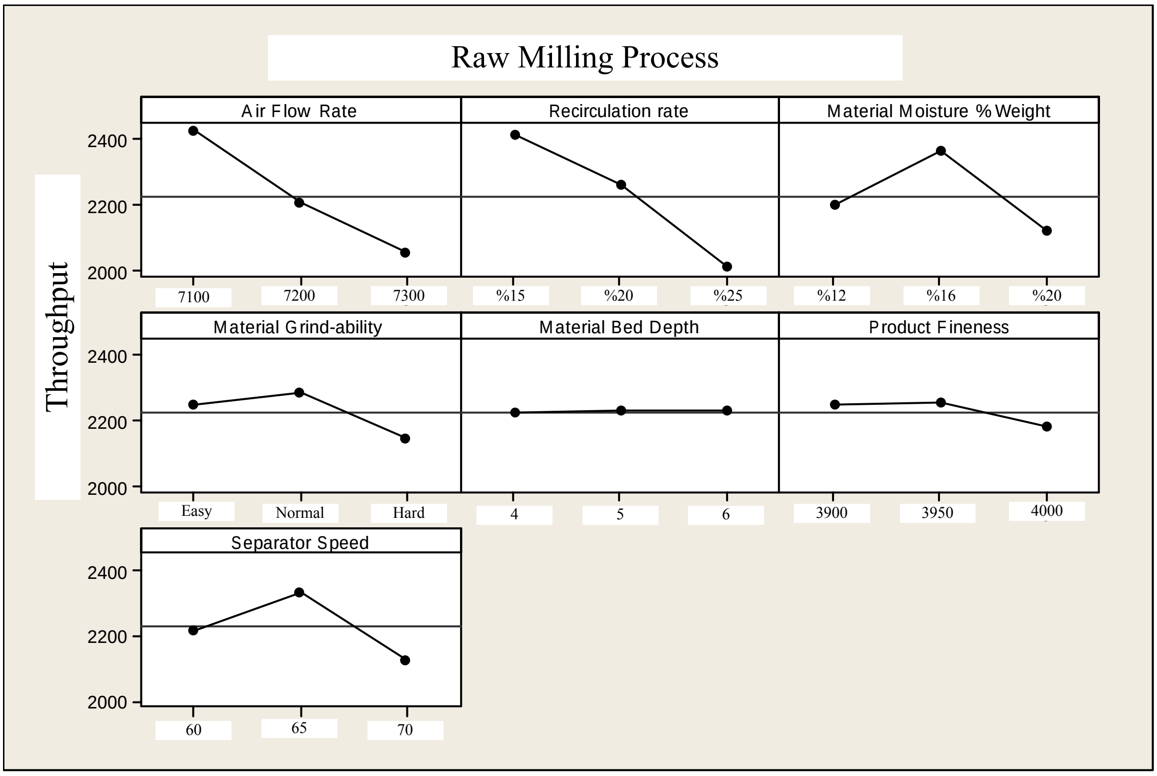

Figure (4): Raw Milling Process Throughput before reducing the WIP.

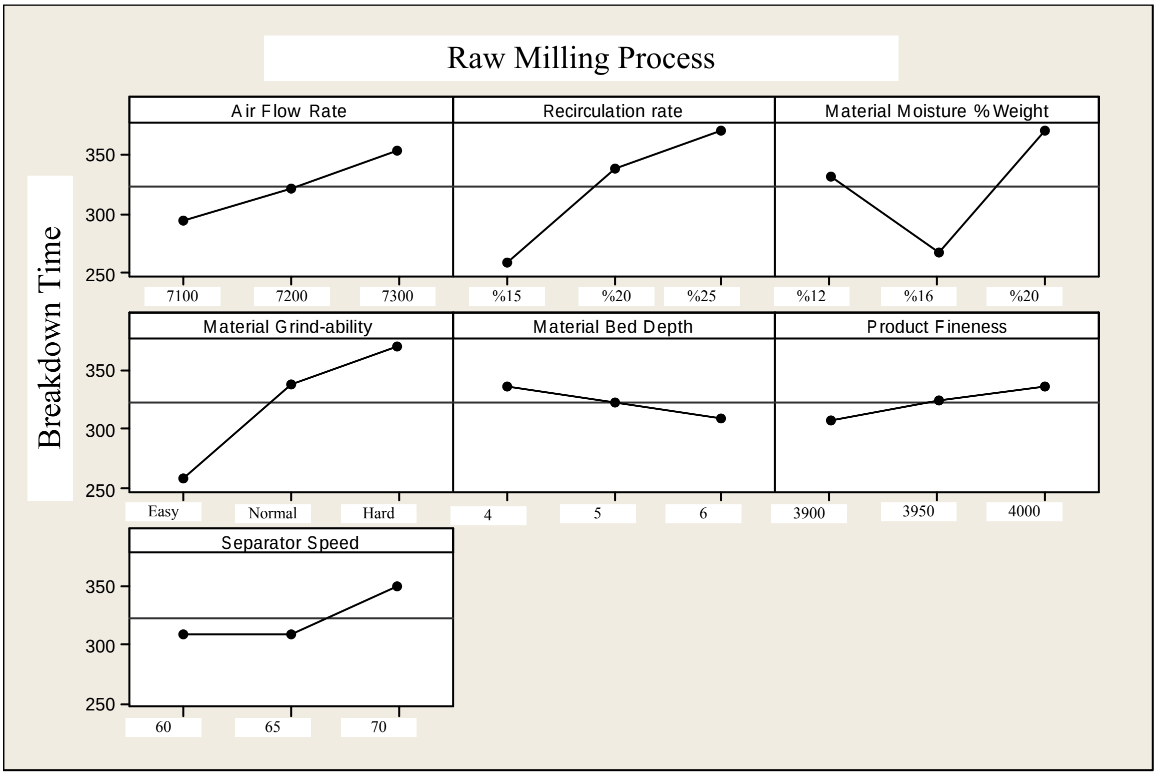

Figure (5): Raw Milling Process Breakdown Time before reducing the WIP.

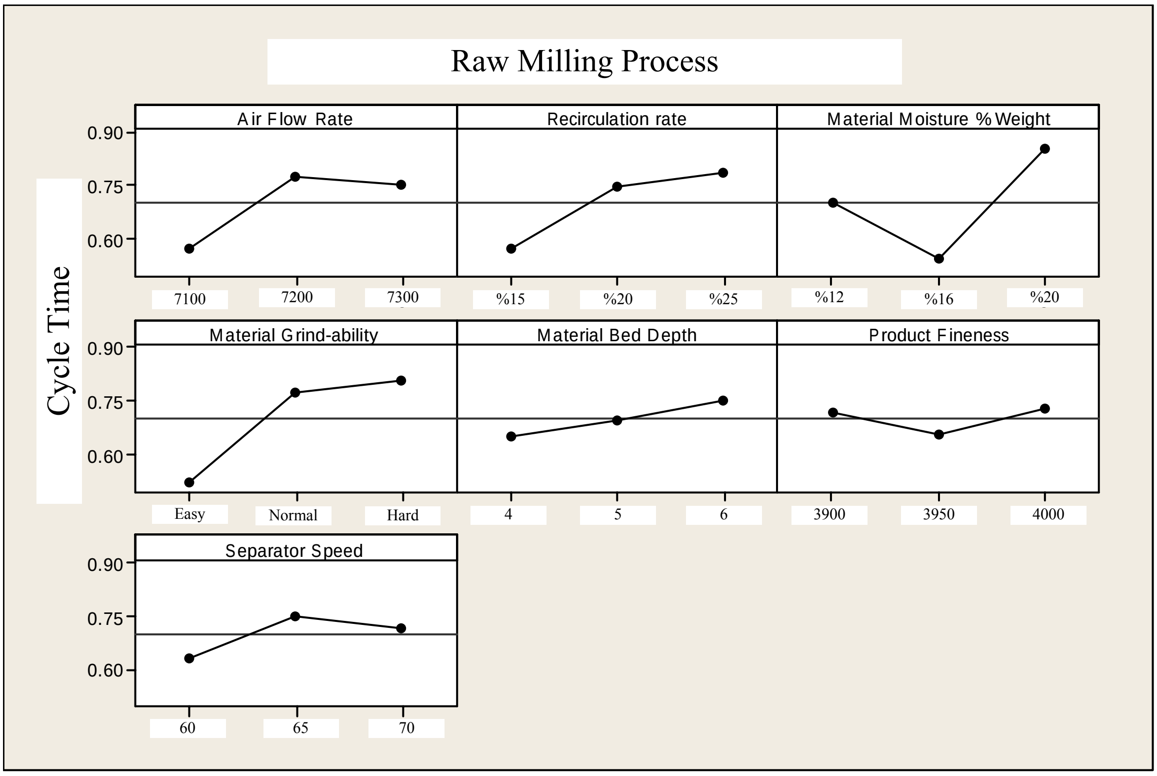

Figure (6): Raw Milling Process Cycle Time before reducing the WIP.

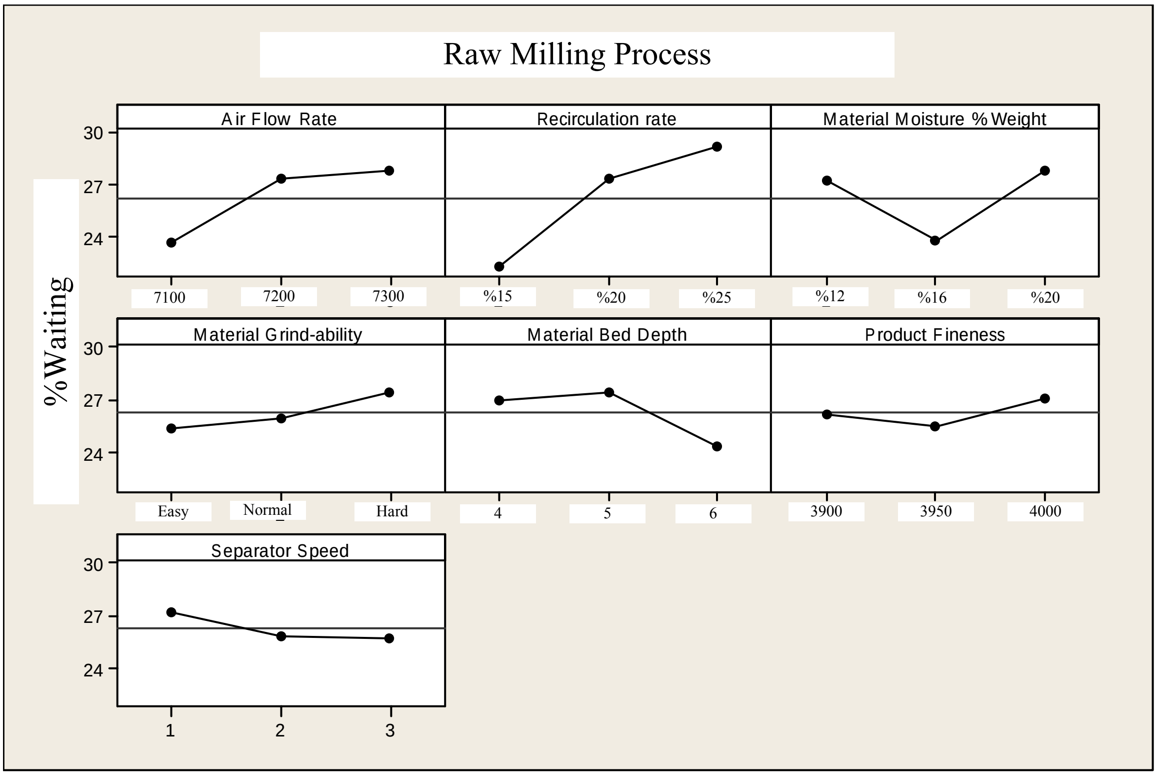

Figure (7): Raw Milling Process %Waiting after reducing the WIP.

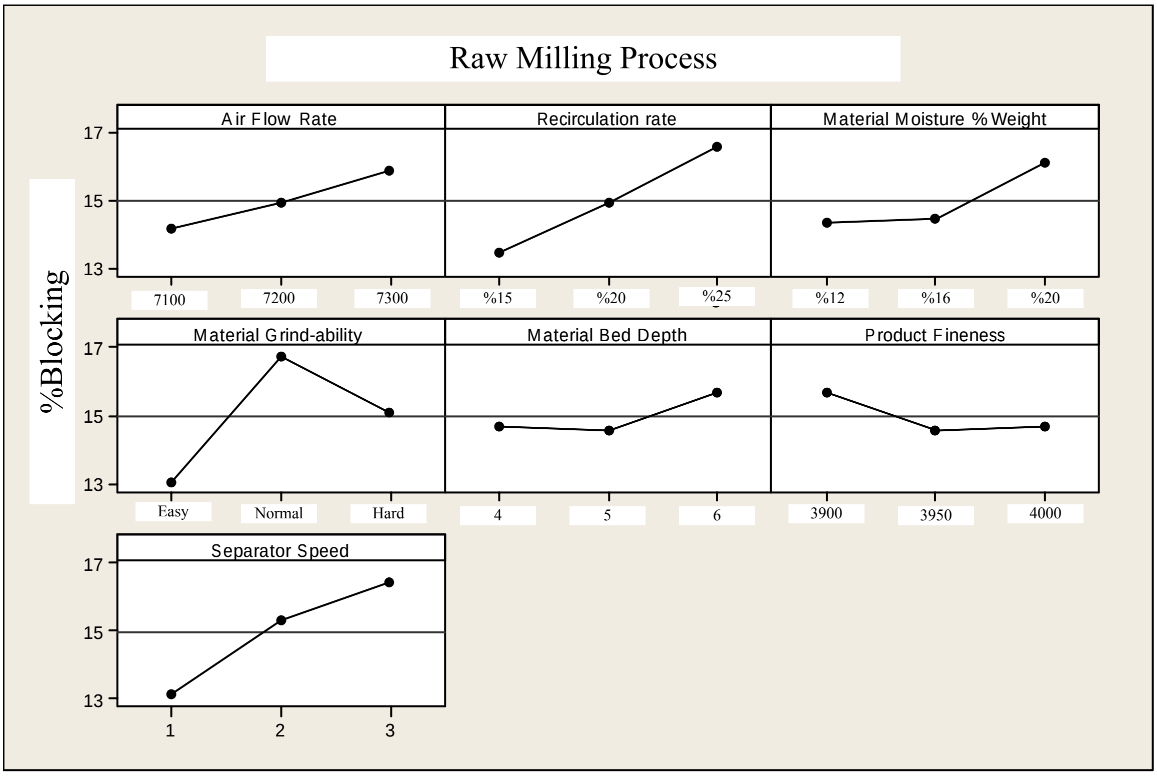

Figure (8): Raw Milling Process %Blocking after reducing the WIP.

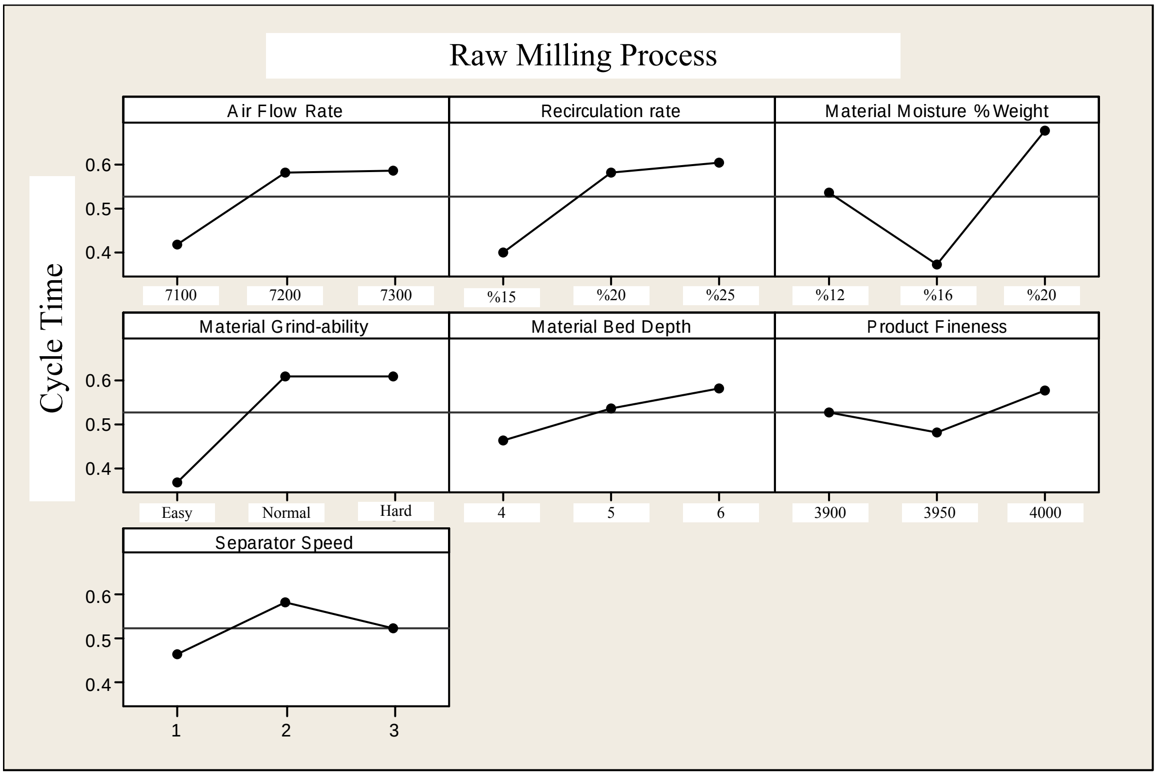

Figure (9): Raw Milling Process Cycle Time after reducing the WIP.

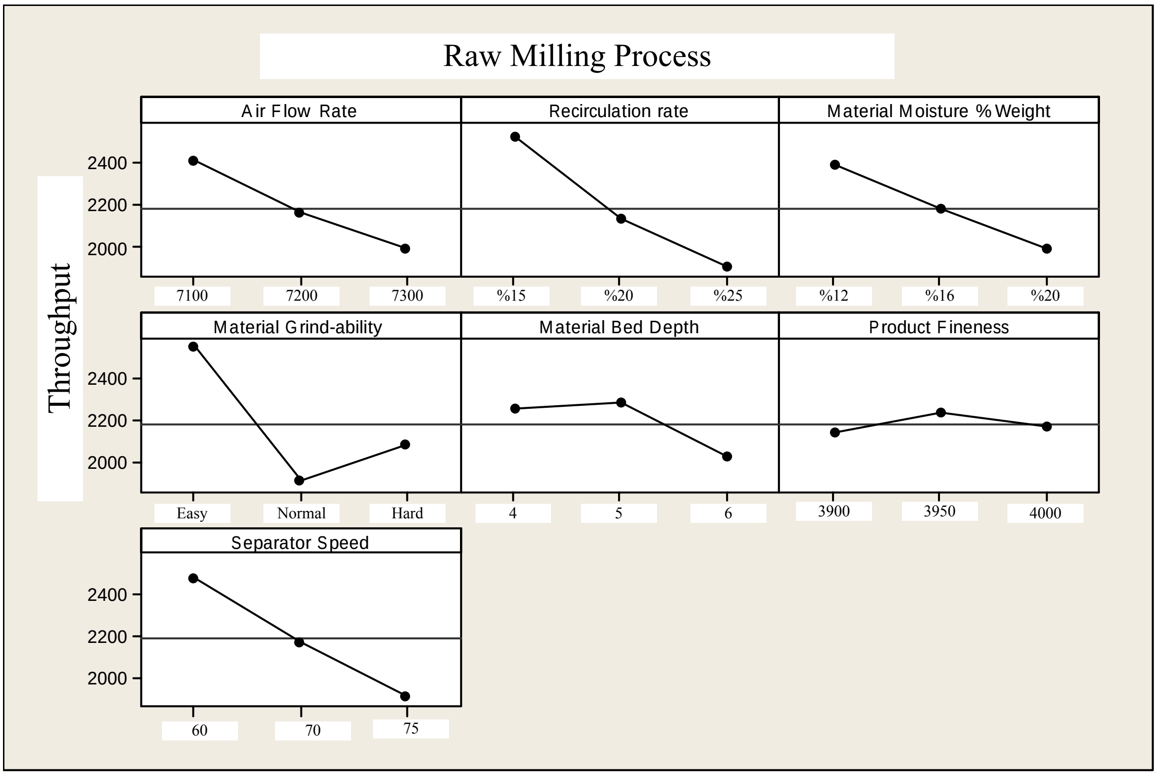

Figure (10): Raw Milling Process Throughput after reducing the WIP.

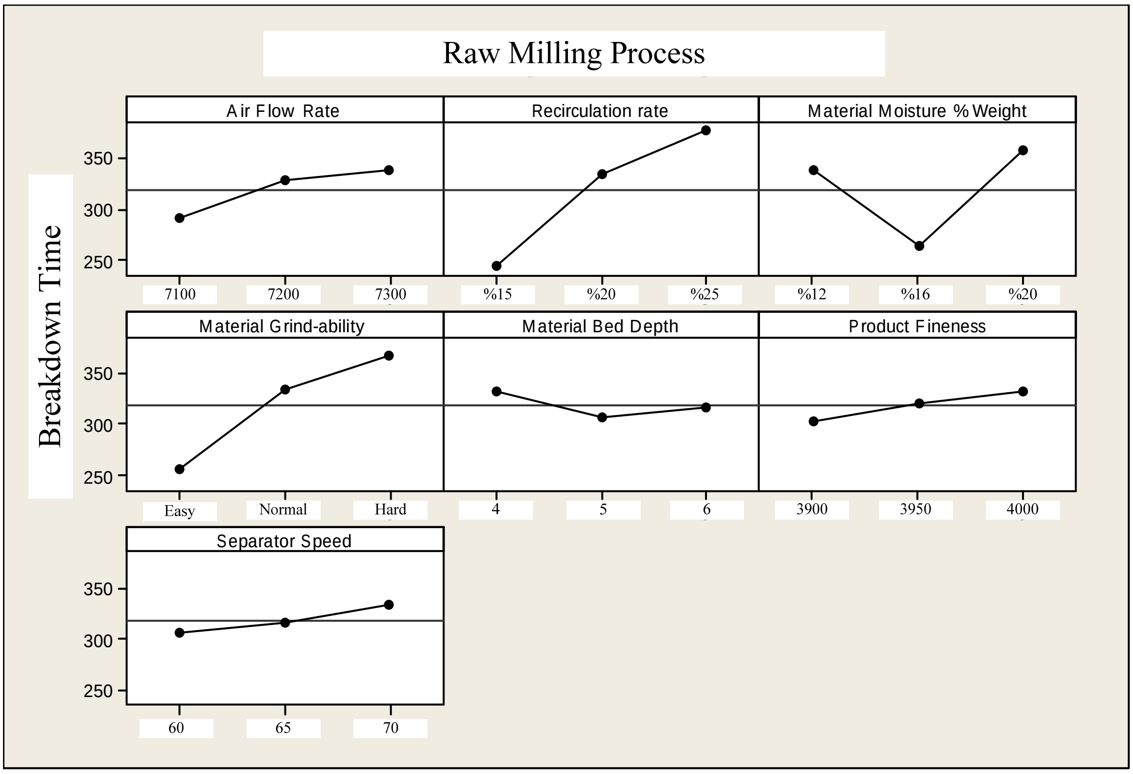

Figure (11): Raw Milling Process Breakdown Time after reducing the WIP.

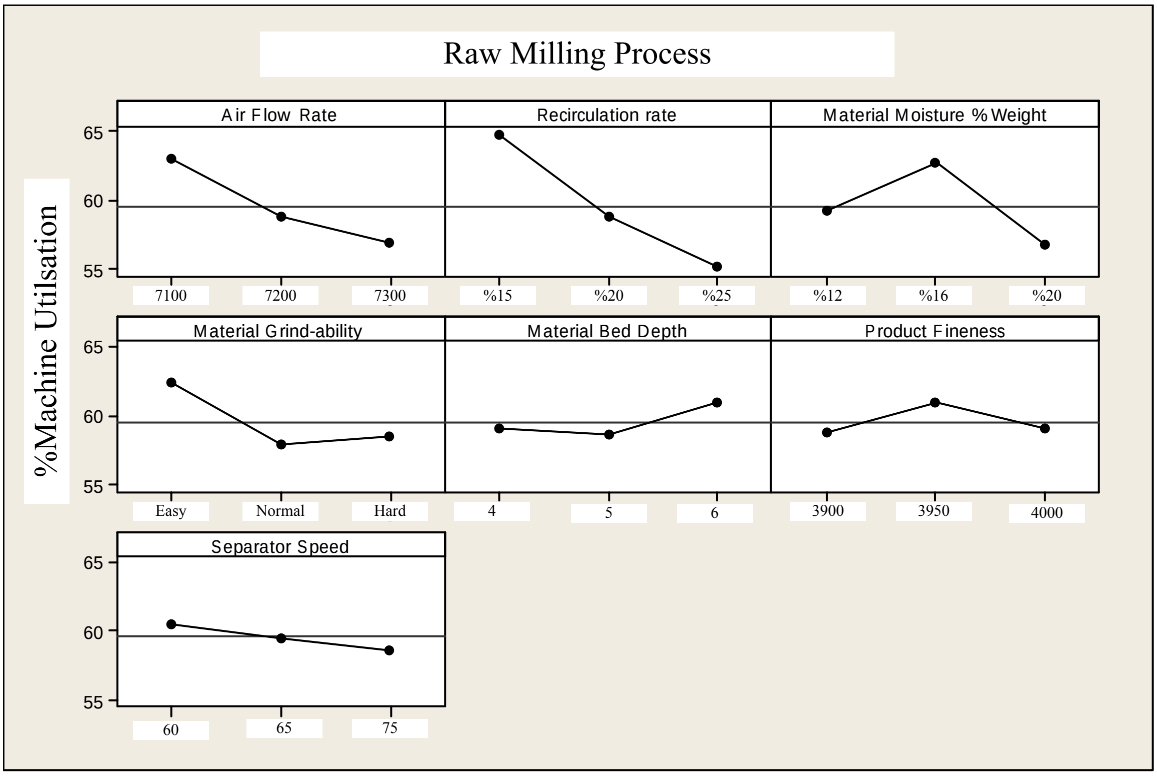

Figure (12): Raw Milling Process %Machine Utilisation after reducing the WIP.

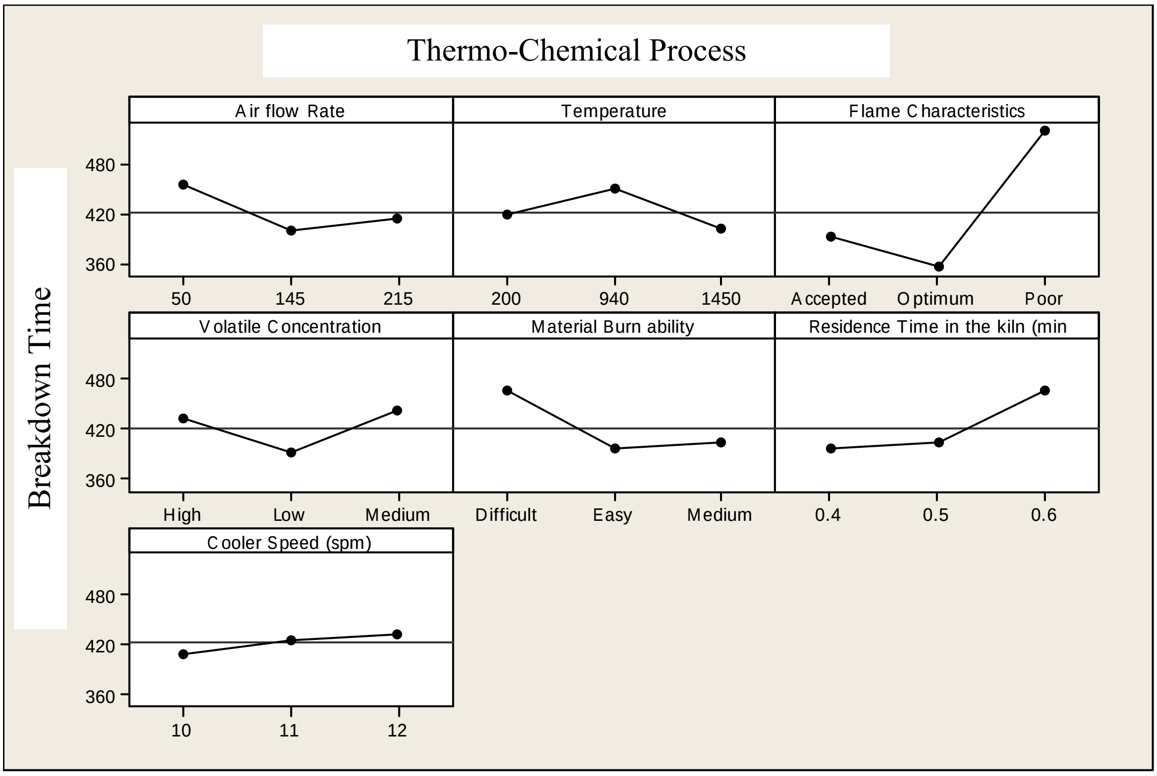

Figure (13): Thermo-Chemical Process Breakdown Time before reducing WIP.

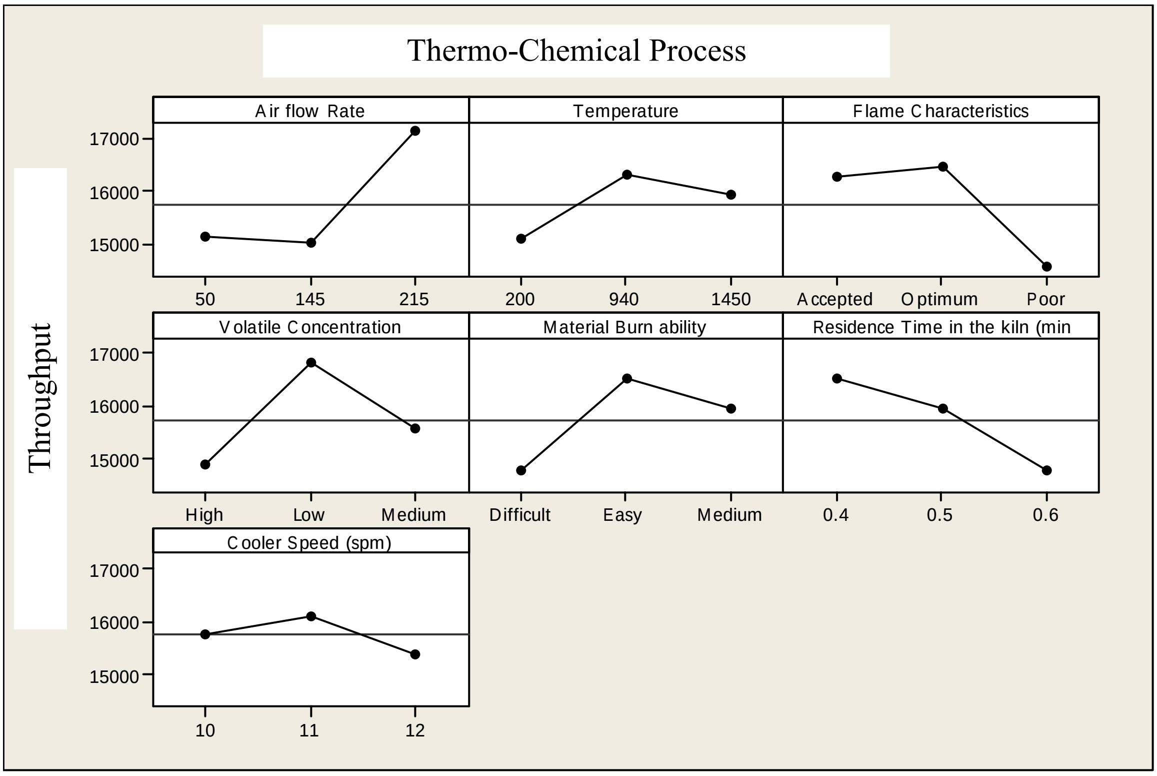

Figure (14): Thermo-Chemical Process Throughput before reducing WIP.

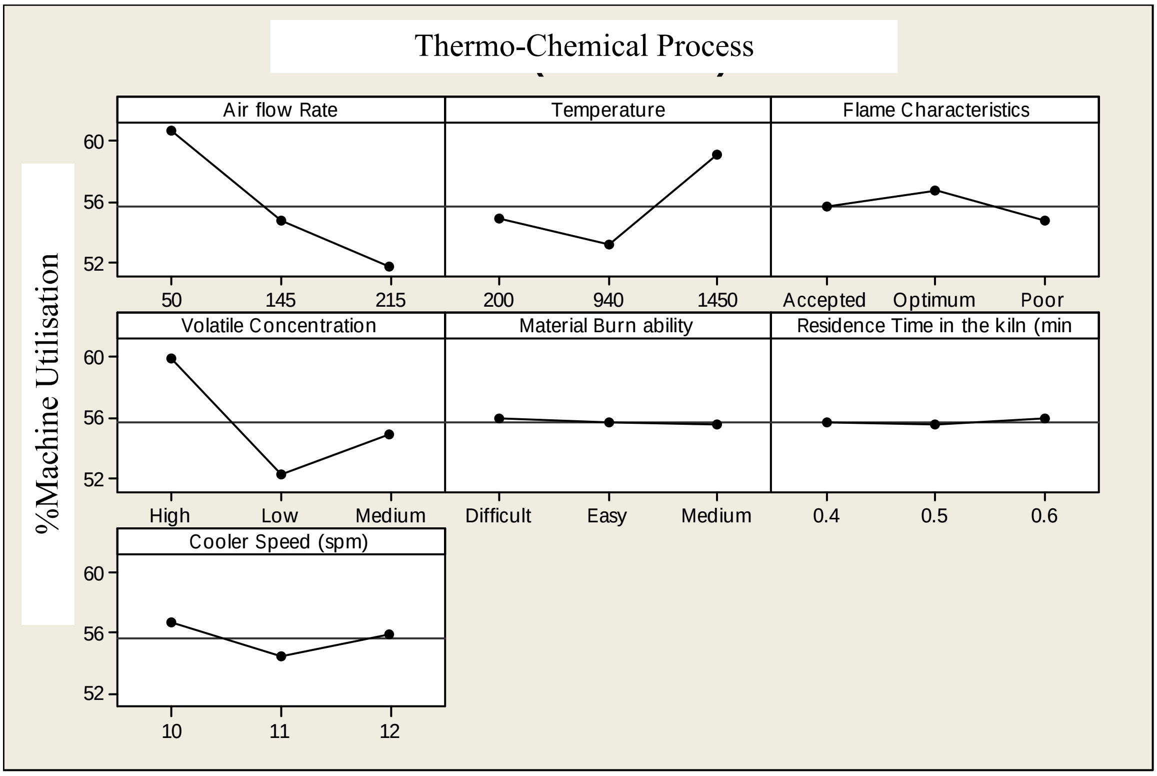

Figure (15): Thermo-Chemical Process %Machine Utilisation before reducing WIP.

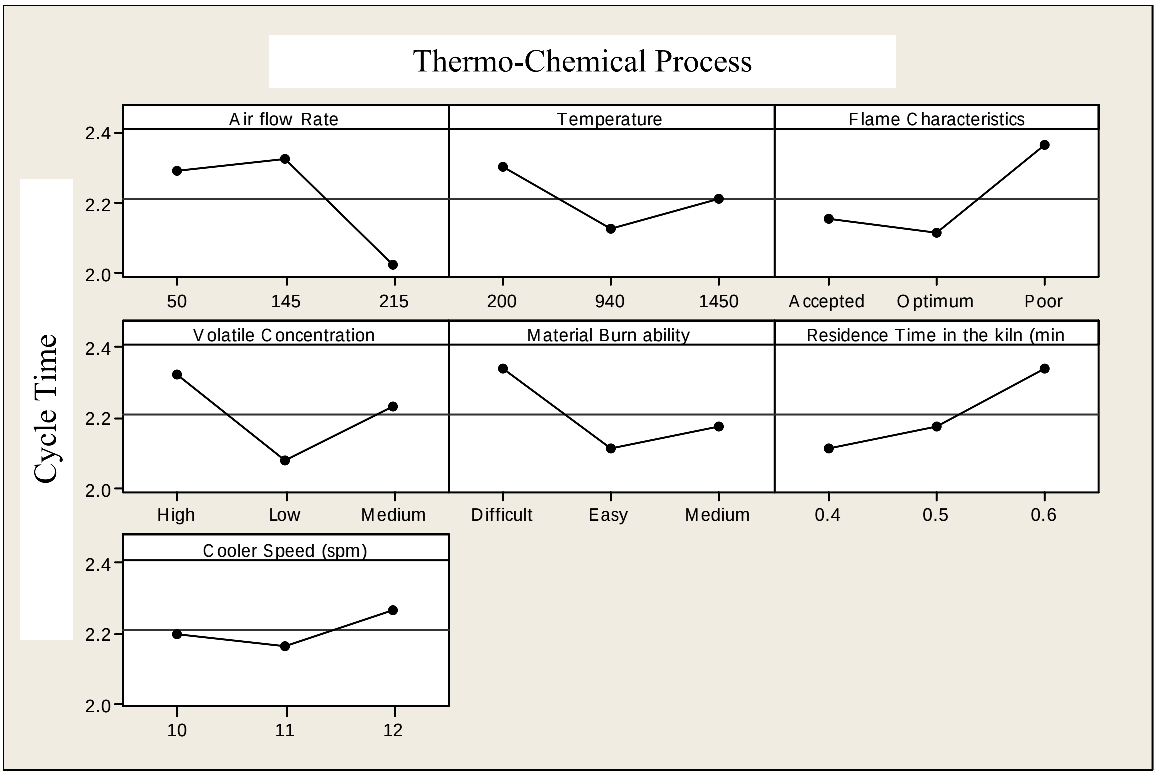

Figure (16): Thermo-Chemical Process Cycle Time before reducing WIP.

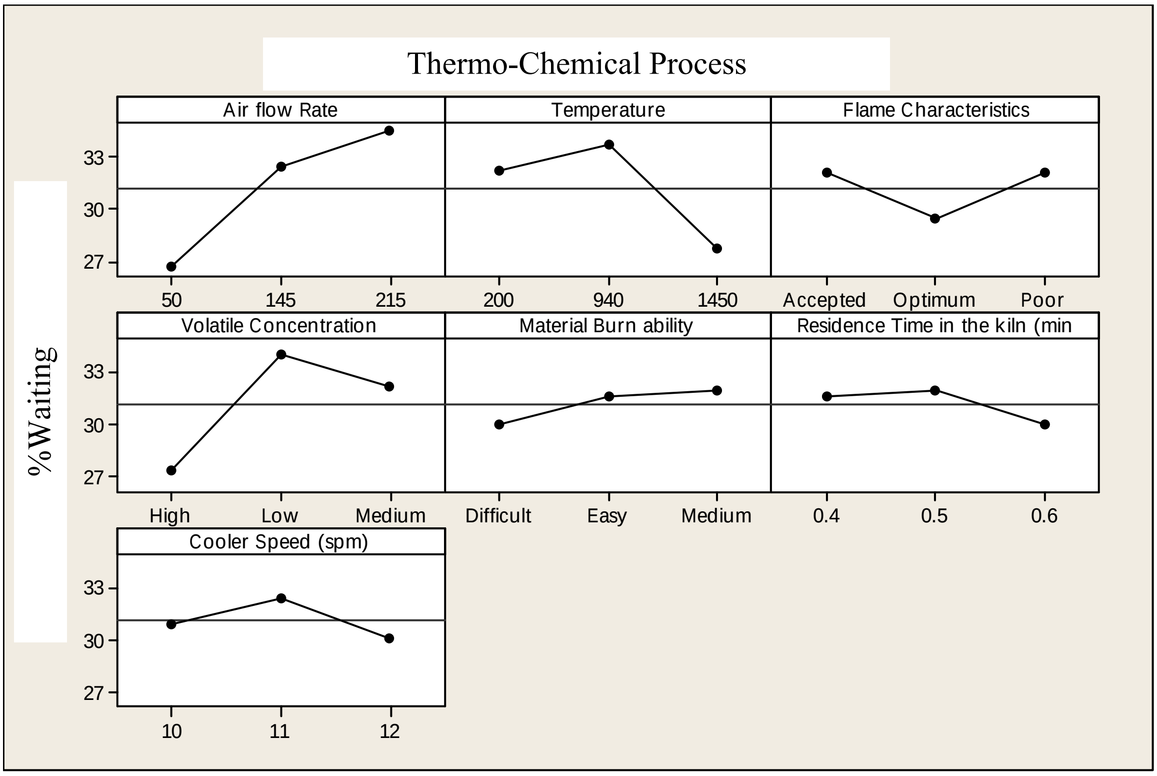

Figure (17): Thermo-Chemical Process %Waiting before reducing WIP.

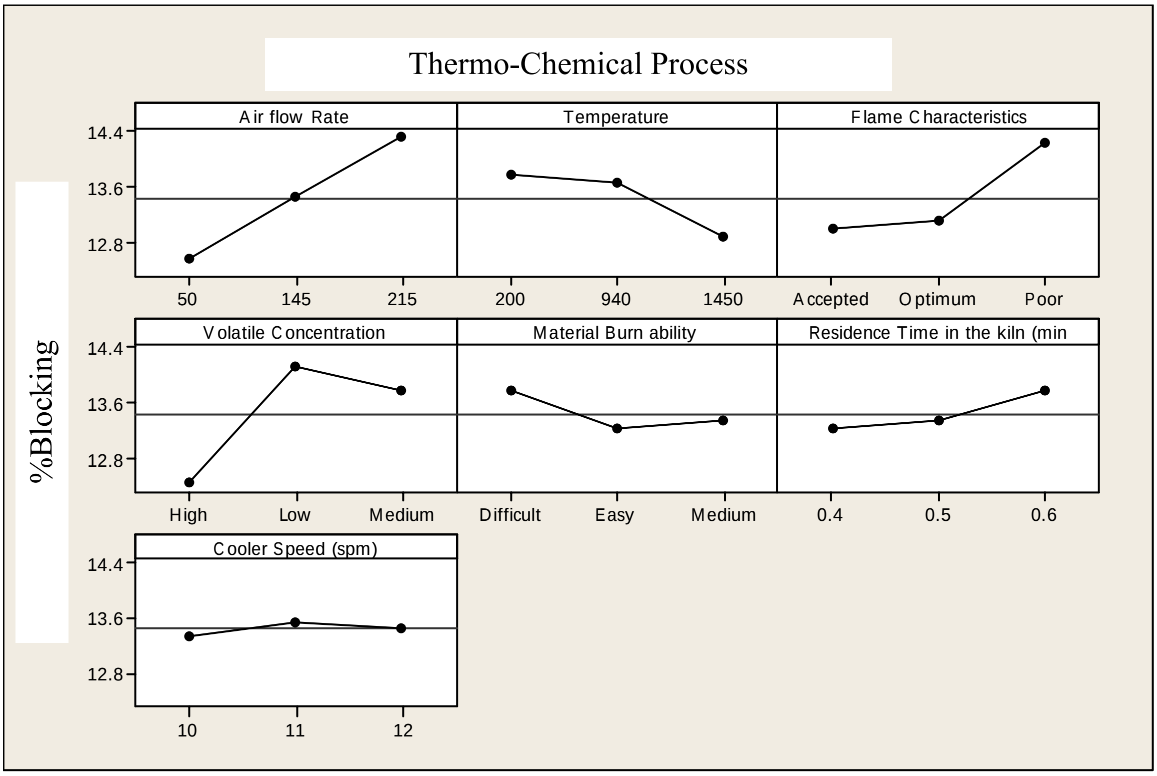

Figure (18): Thermo-Chemical Process %Blocking before reducing WIP.

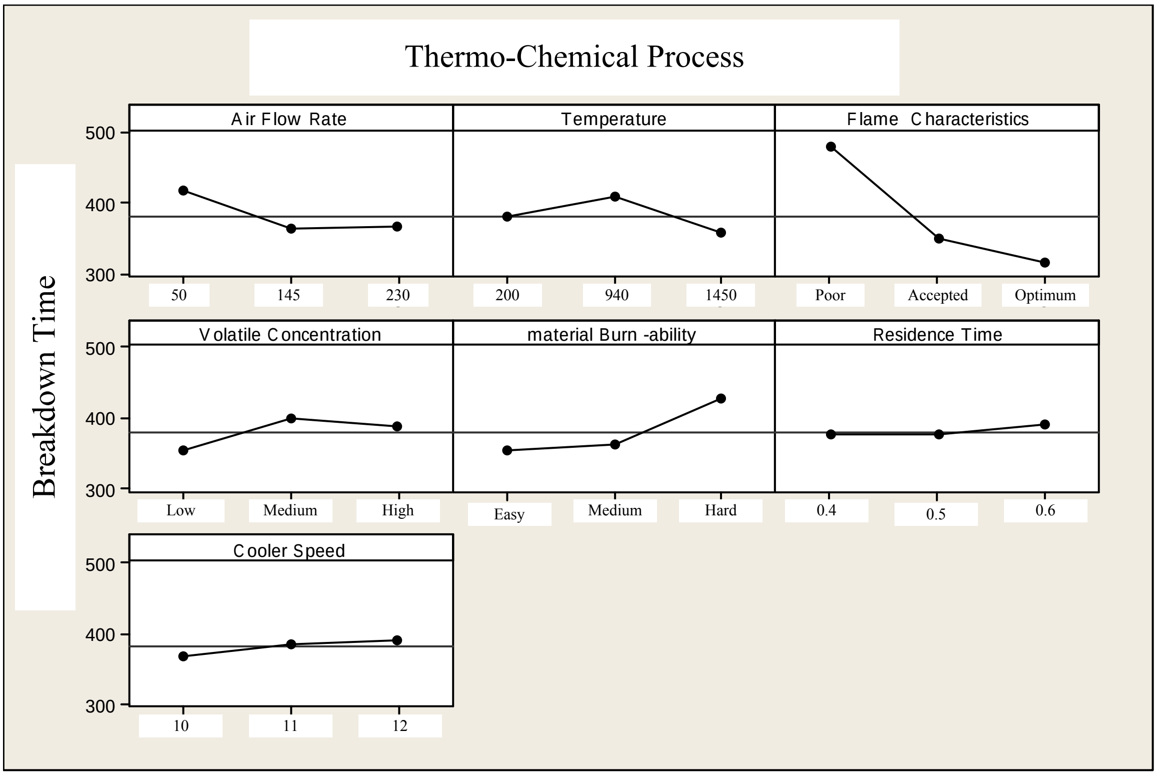

Figure (19): Thermo-Chemical Process Breakdown Time after reducing WIP.

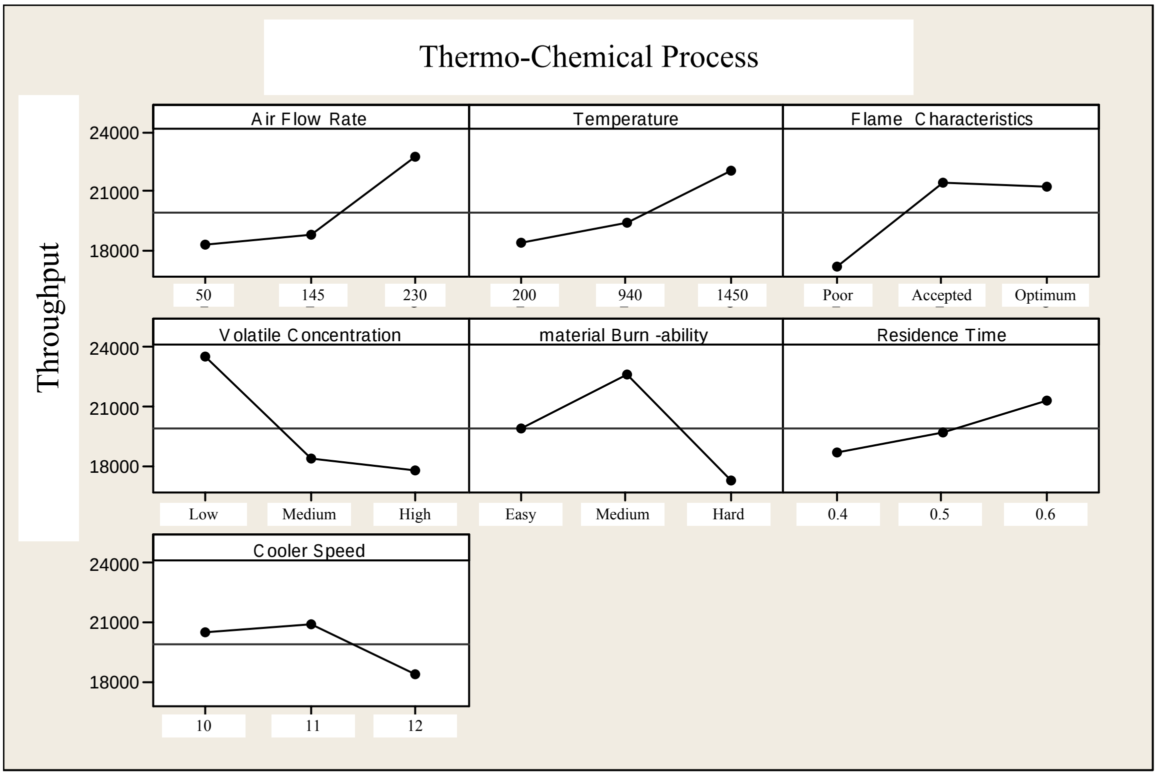

Figure (20): Thermo-Chemical Process Throughput after reducing WIP.

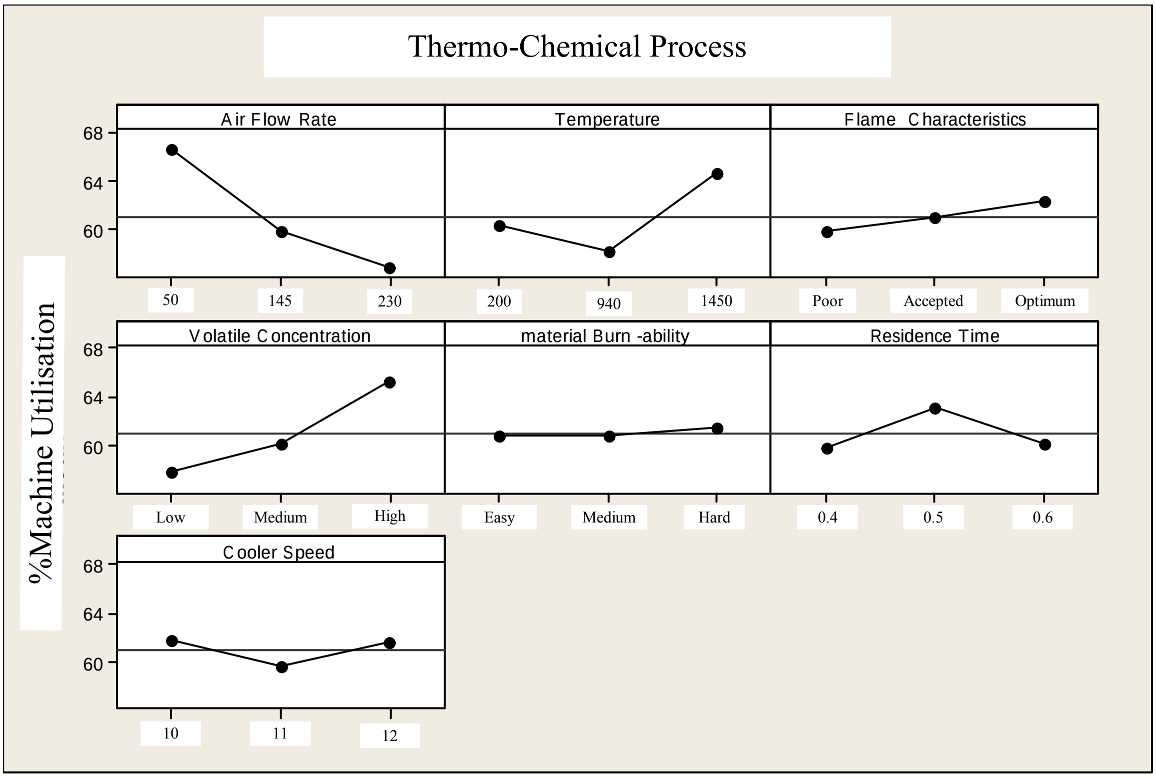

Figure (21): Thermo-Chemical Process %Machine Utilisation after reducing WIP.

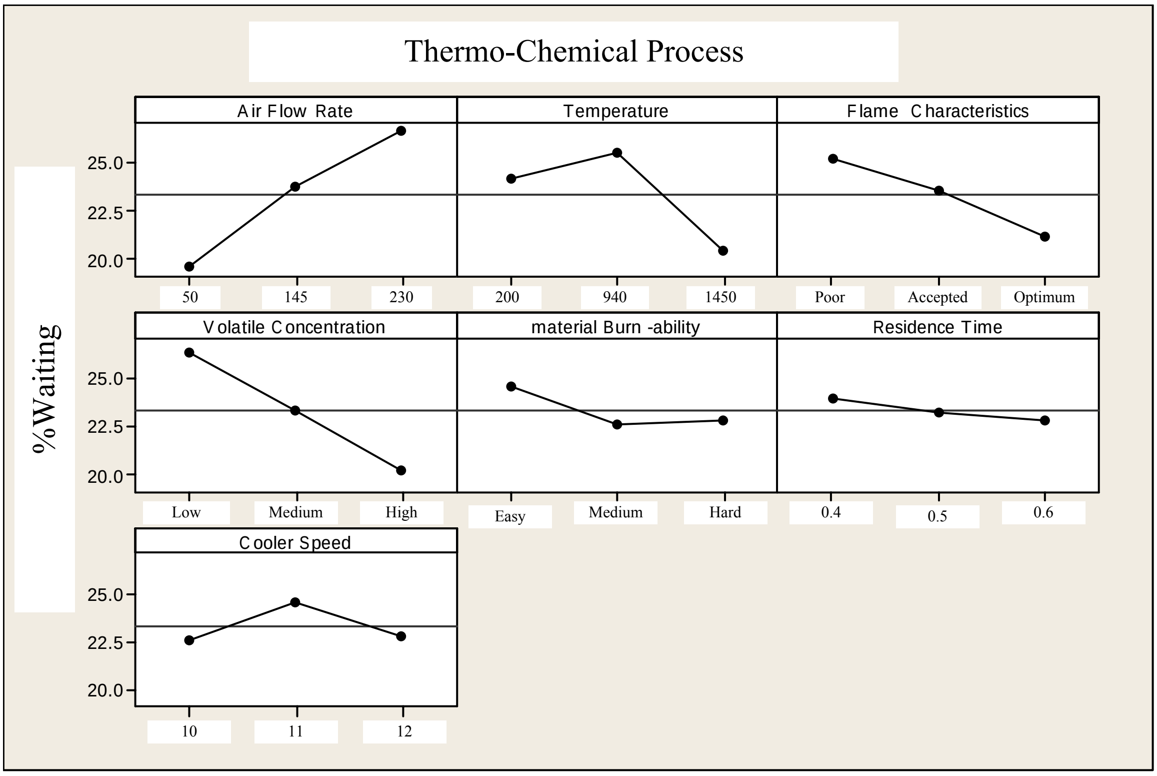

Figure (22): Thermo-Chemical Process %Waiting after reducing WIP.

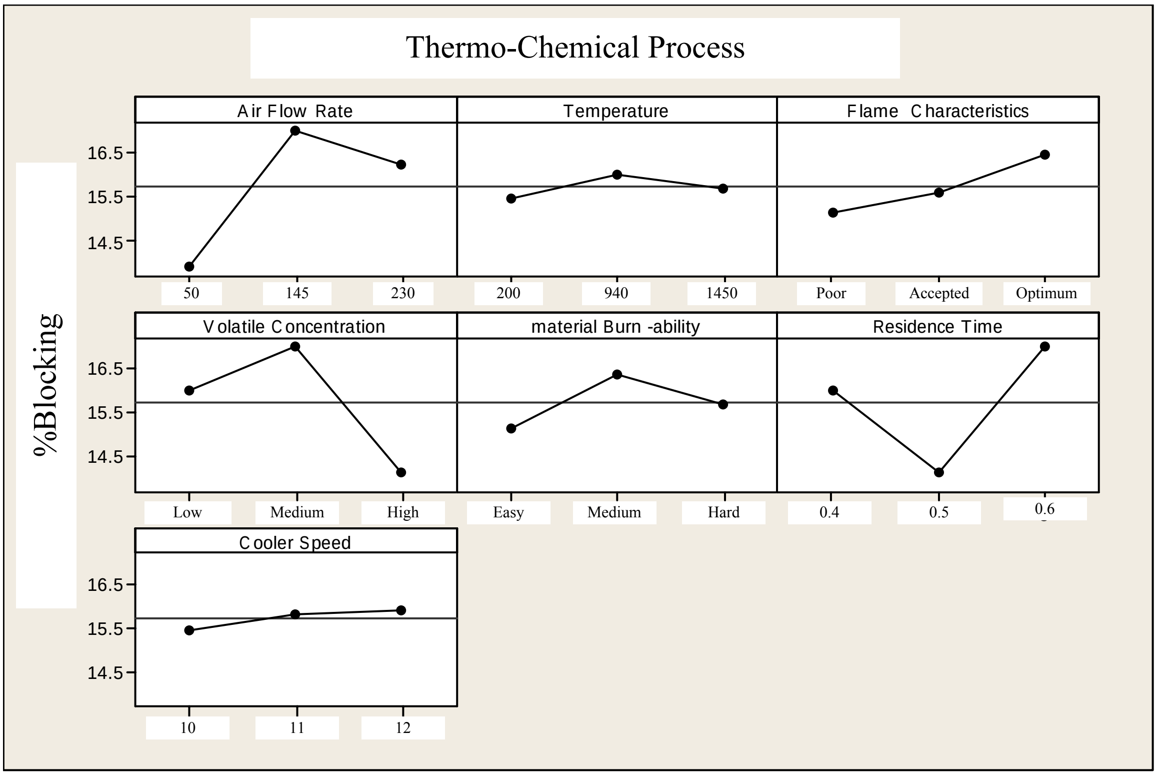

Figure (23): Thermo-Chemical Process %Blocking after reducing WIP.

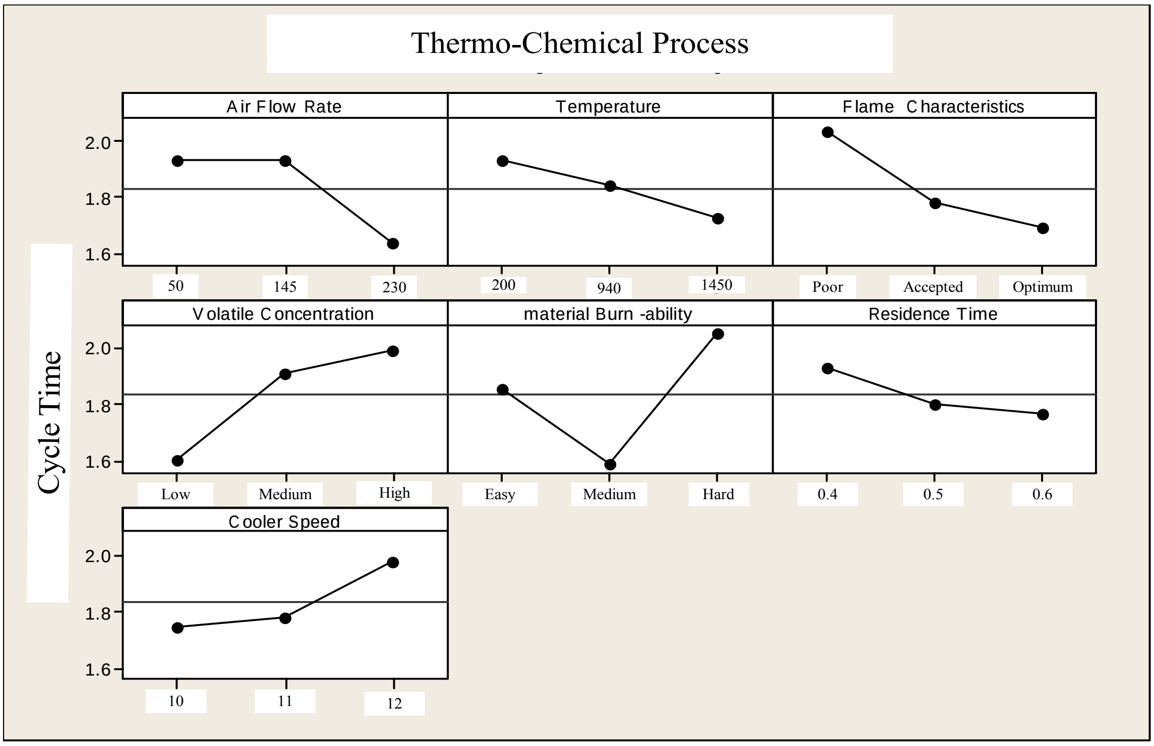

Figure (24): Thermo-Chemical Process Cycle Time after reducing WIP.

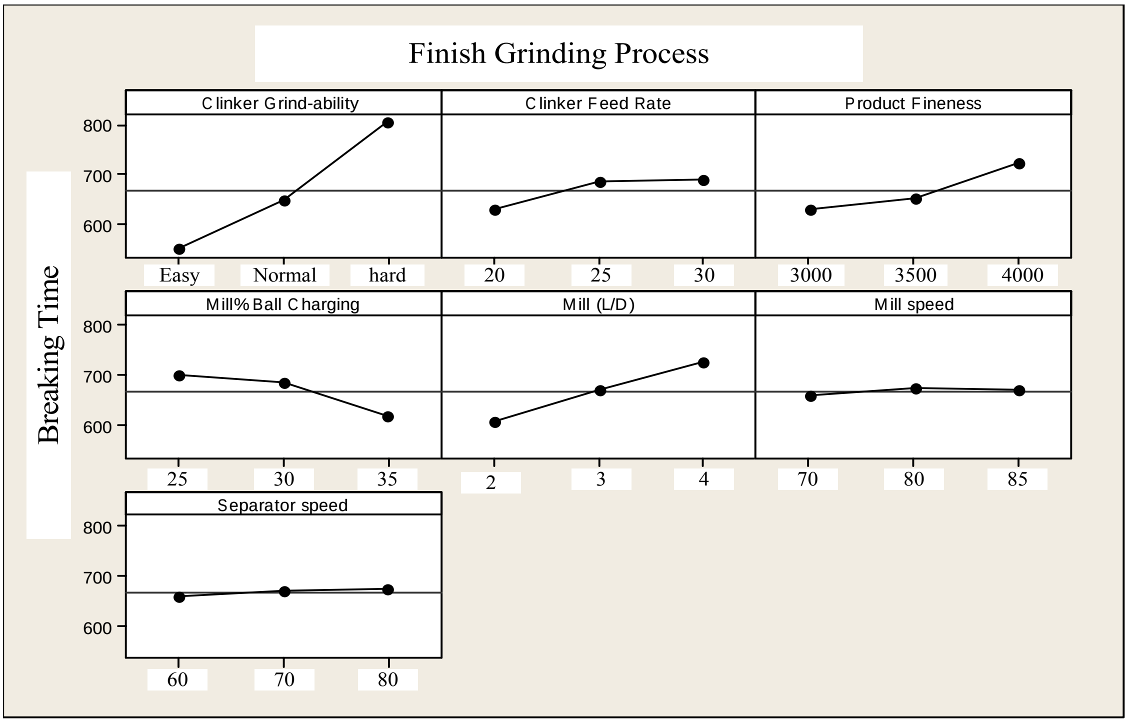

Figure (25): Finish Grinding Process Breaking Time before reducing WIP.

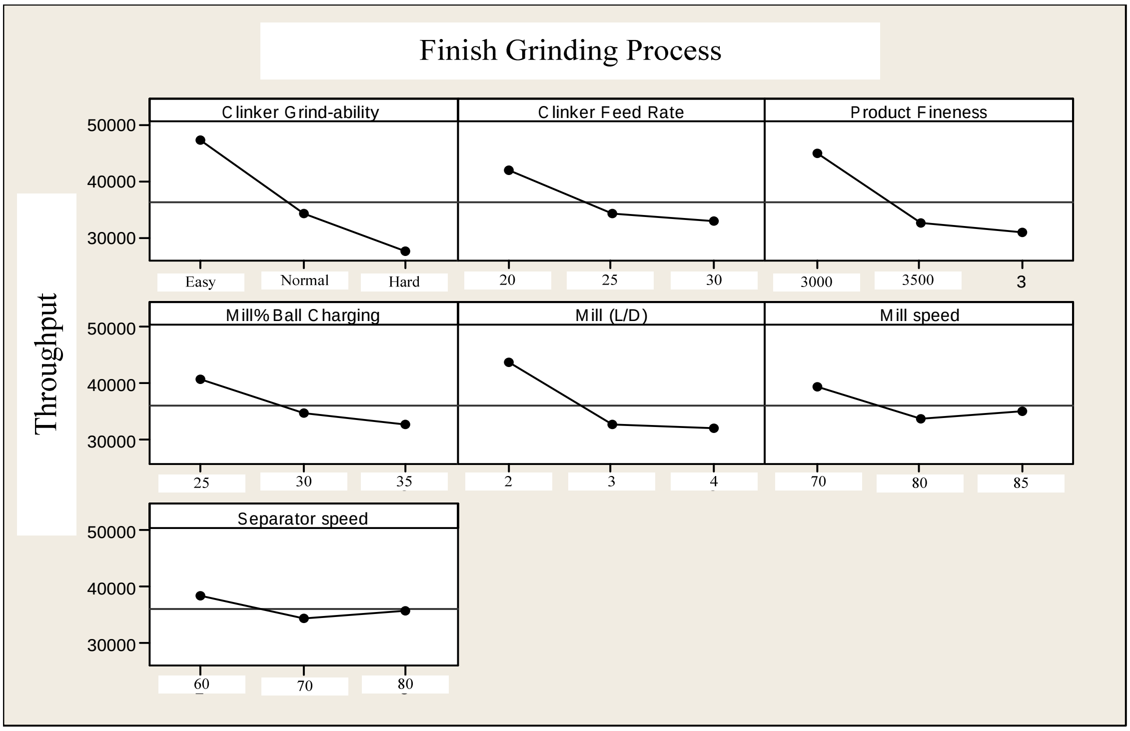

Figure (26): Finish Grinding Process Throughput before reducing WIP.

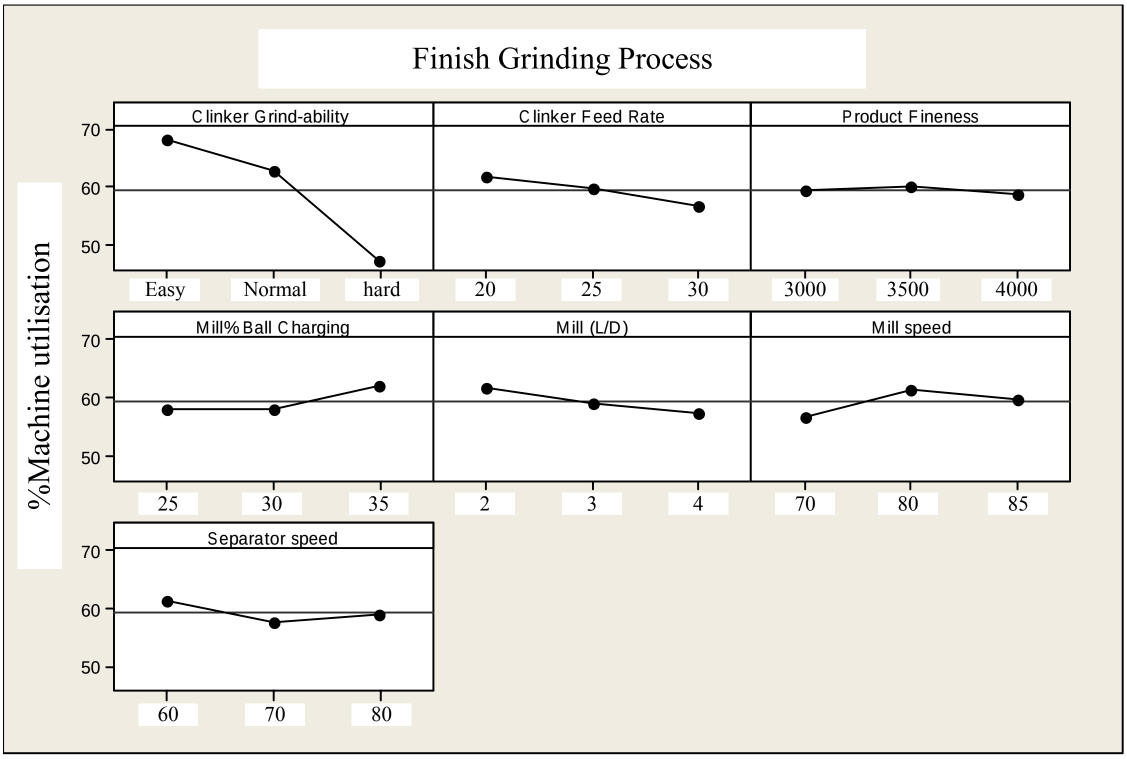

Figure (27): Finish Grinding Process %Machine Utilisation before reducing WIP.

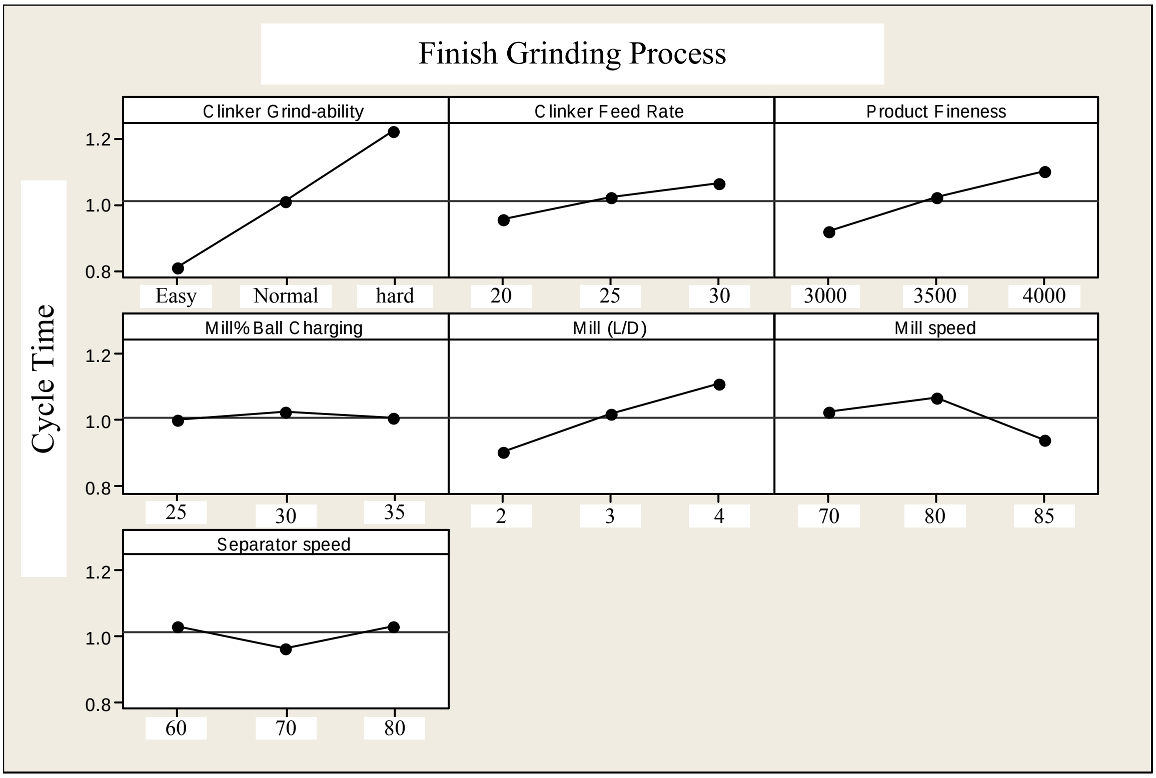

Figure (28): Finish Grinding Process Cycle Time before reducing WIP.

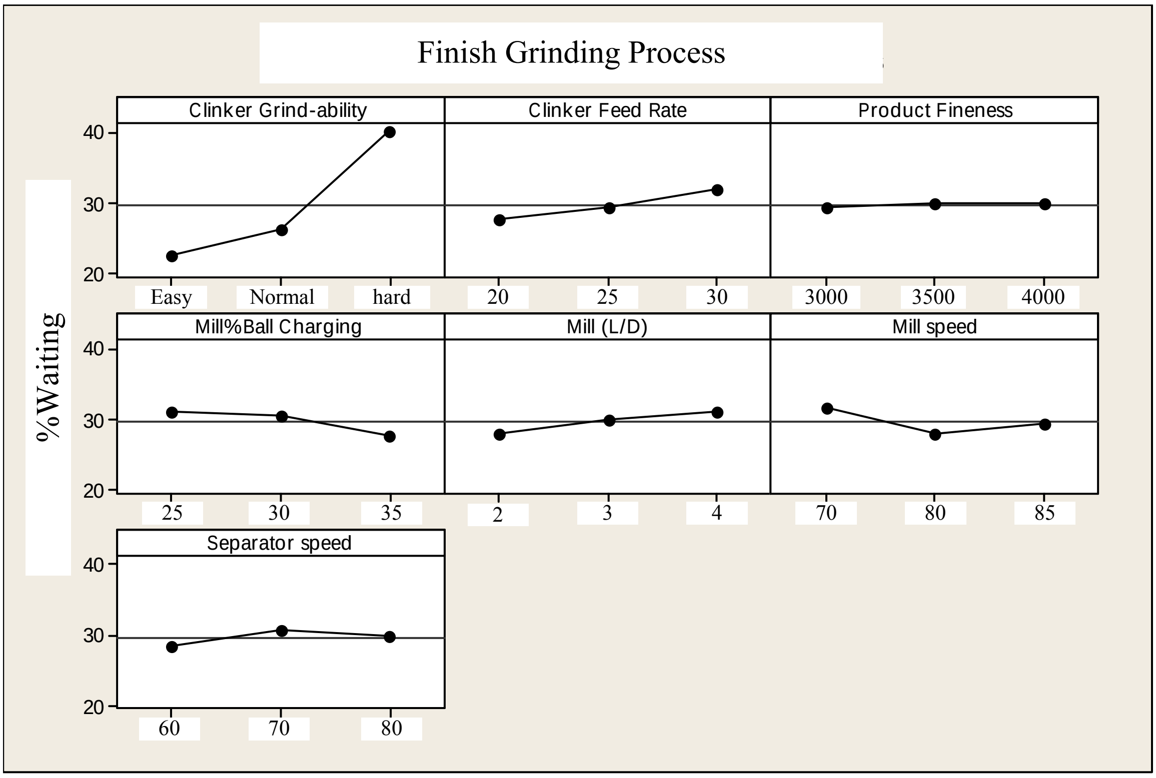

Figure (29): Finish Grinding Process %Waiting before reducing WIP.

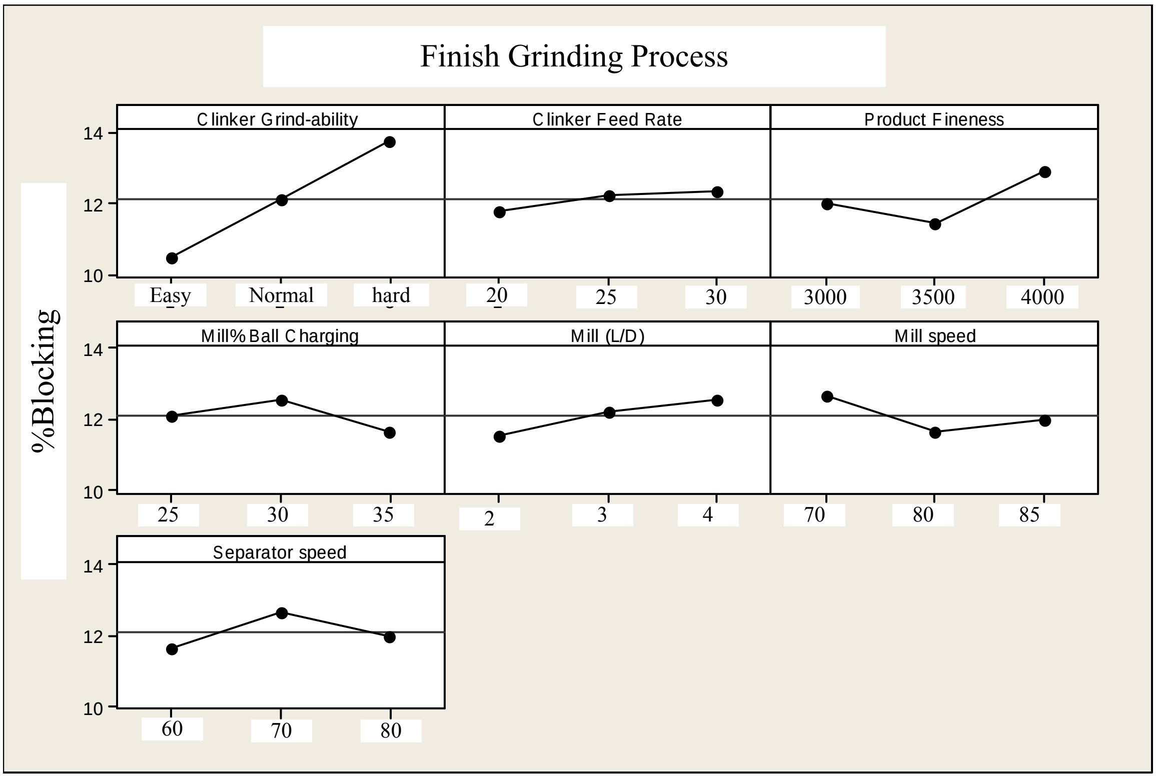

Figure (30): Finish Grinding Process %Blocking before reducing WIP.

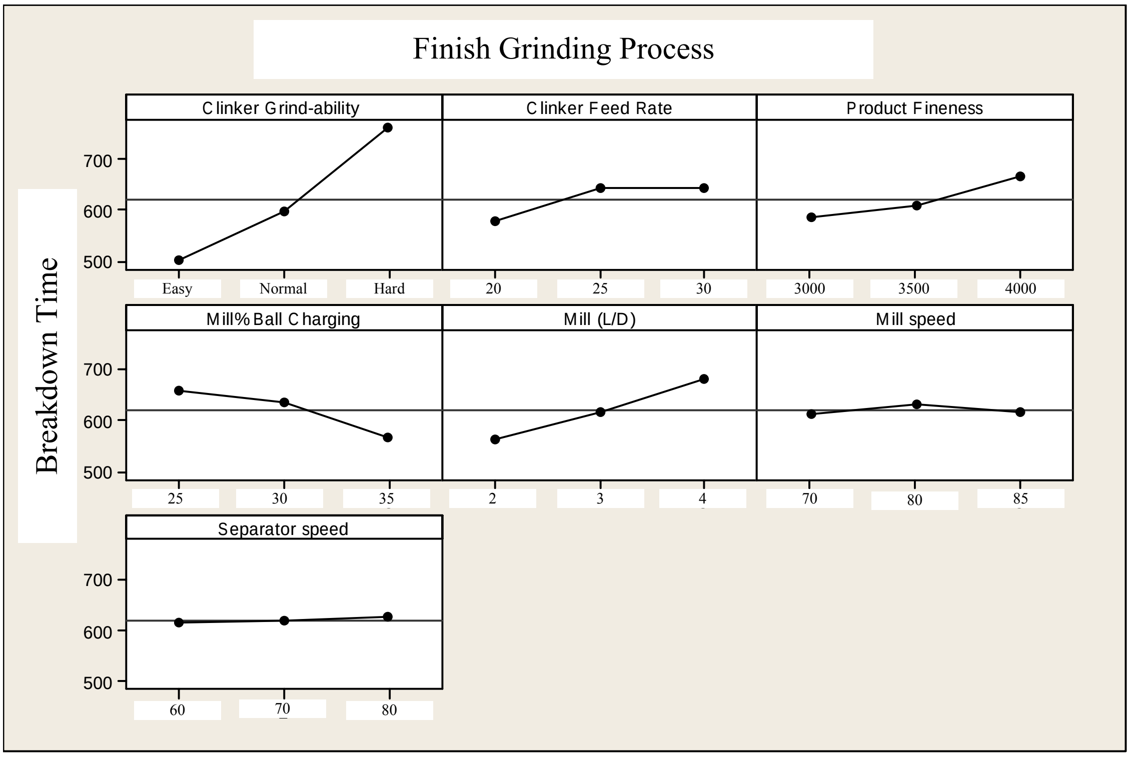

Figure (31): Finish Grinding Process Breakdown Time after reducing WIP.

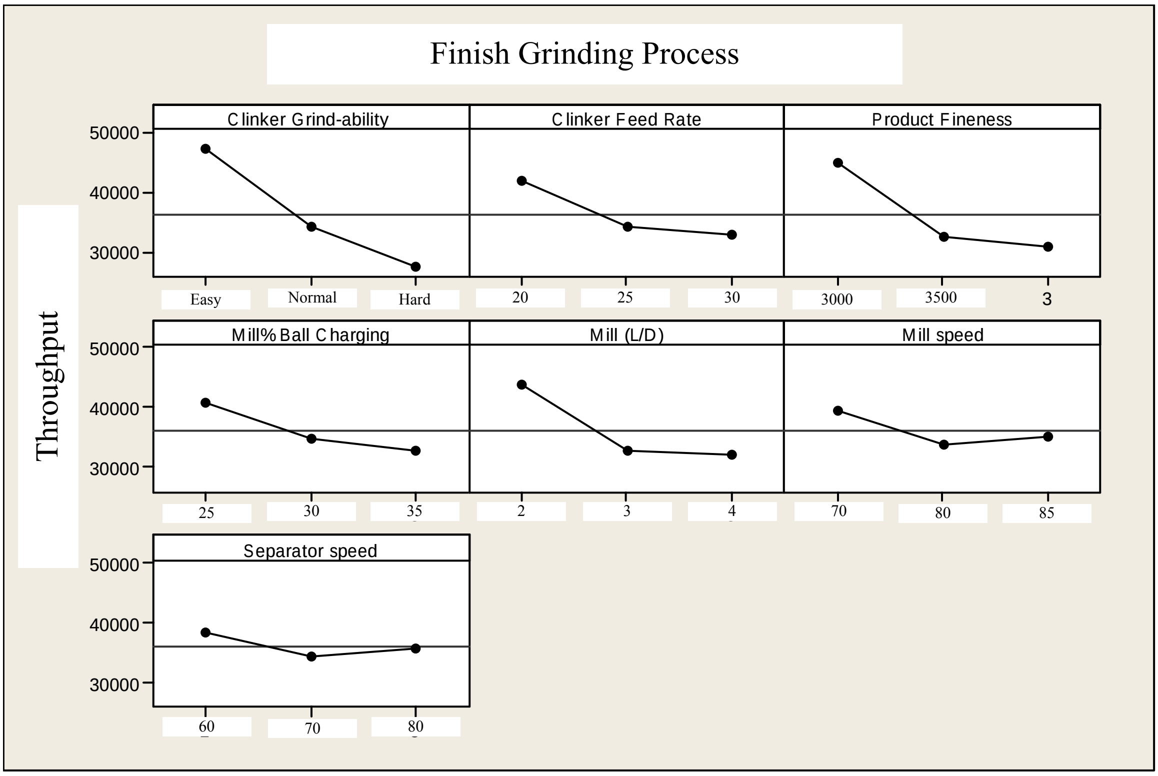

Figure (32): Finish Grinding Process Throughput after reducing WIP.

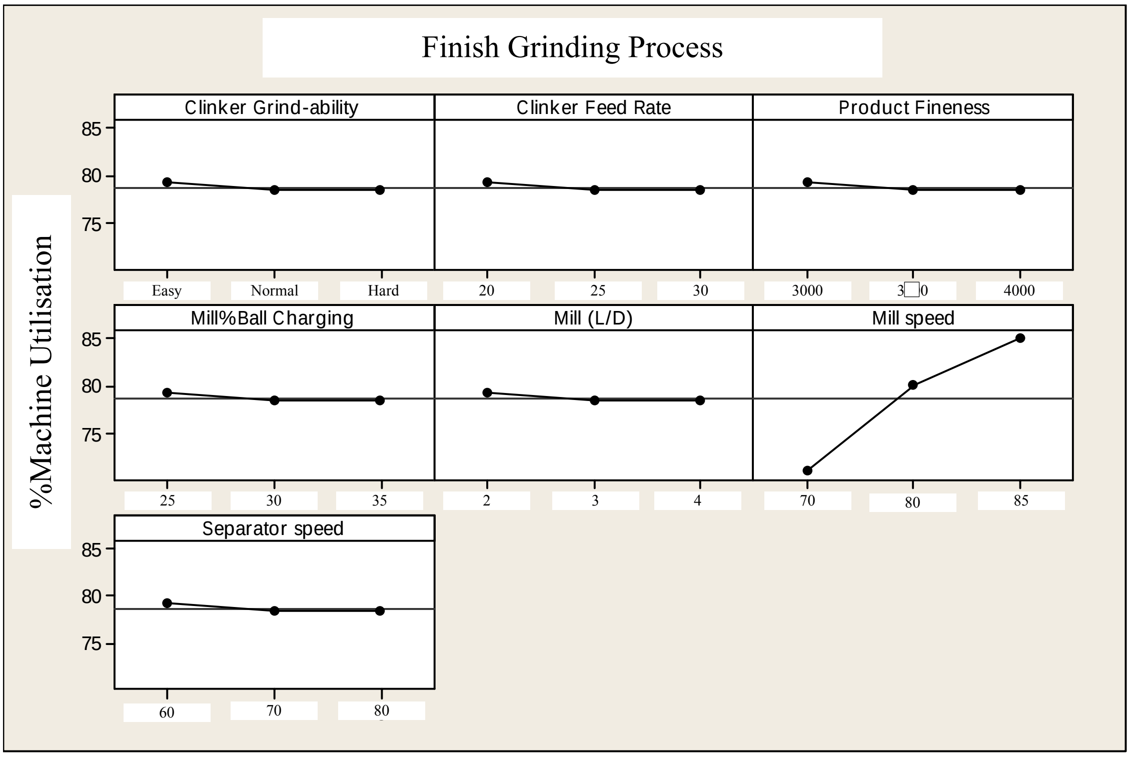

Figure (33): Finish Grinding Process %Machine utilisation after reducing WIP.

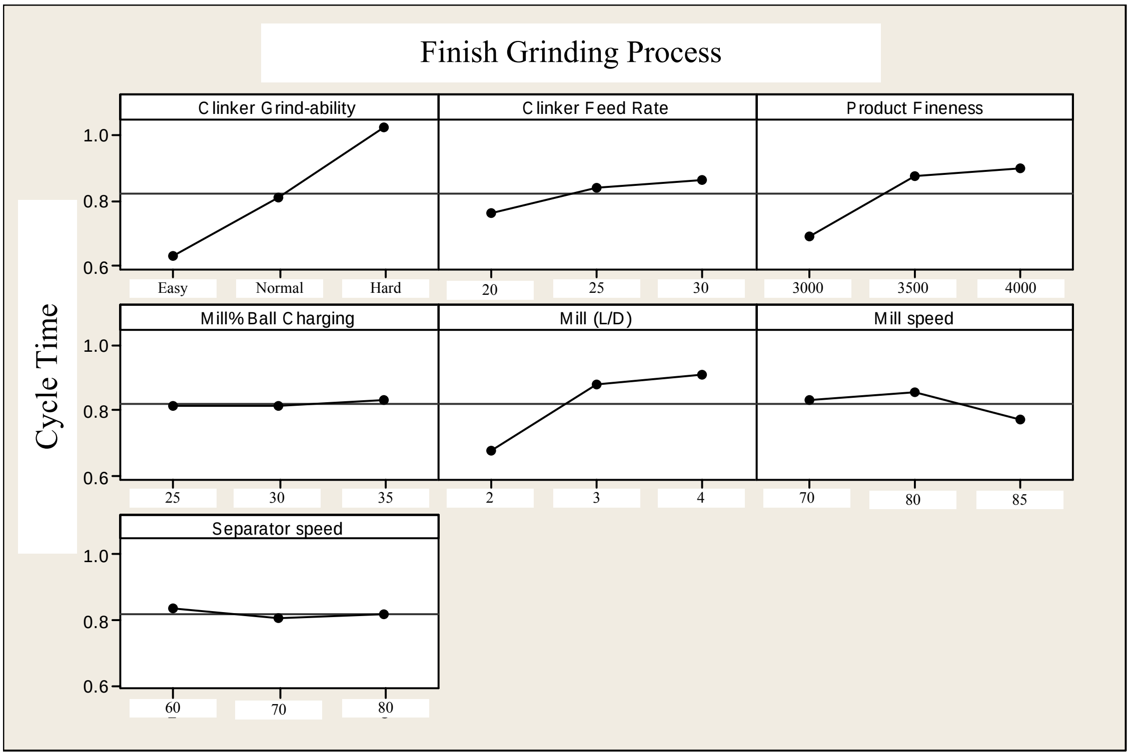

Figure (34): Finish Grinding Process Cycle Time after reducing WIP.

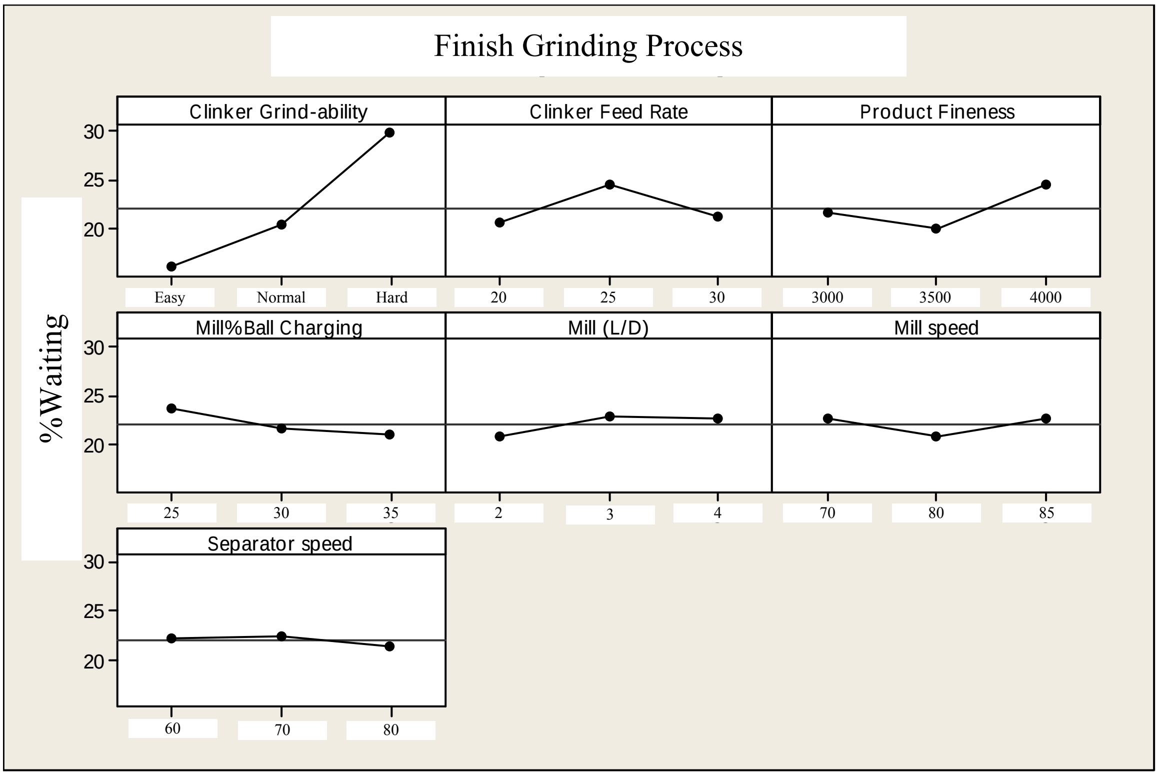

Figure (35): Finish Grinding Process %Waiting after reducing WIP.

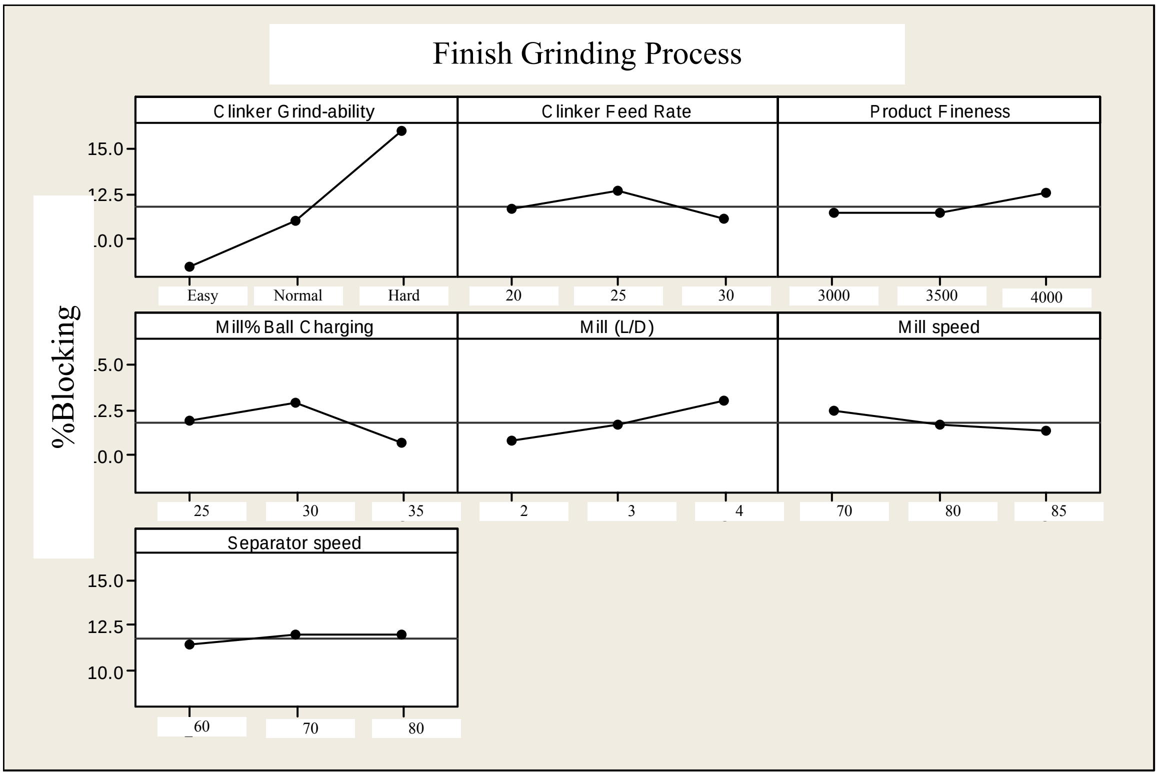

Figure (36): Finish Grinding Process %Blocking after reducing WIP.