Implenetaion of lean in coutinuous Process-based Industries

Khalil, R. A., Stockton, D. J., Tourki T., Mukhongo L.M

Abstract— Lean engineering is a proven method for reducing waste in a production process and increasing its efficiency. It has been successfully employed across a range of industries and services but is most associated with the production of discrete products. Lean represents a major advance over traditional mass production methods. This paper describes work undertaken to implement lean practices in the continuous process sector as represented by cement production. One of the major barriers to lean implementation is providing evidence of its potential benefit to end-users. This work aims to overcome this obstacle by producing a tool which can be used to easily visualise the benefits of adopting lean practices without requiring disruption to the production environment.

This paper describes a methodology for data collection, knowledge extraction, model creation and experimentation that combines the use of process mapping, computational simulation and the Taguchi method for Design of Experiments. A detailed description of each step of the process is given and is illustrated by results from a case study undertaken during the research. Experiments performed to evaluate lean improvements against current production methods for cement production are given and clearly demonstrate the utility of the approach and have helped to convey the lean message to industry end-users

Index Terms— Lean manufacturing, cement production, simulation, and process improvement

◆

1 INTRODUCTION

Implementation of lean has helped many organisations to improve their productivity and efficiency. Lean originated in the automobile manufacturing sector and has spread widely within the discrete production industries. The current challenge is to implement the lean philosophy within non-discrete production environments such as continuous manufacturing industries and service industries regardless to the type, size, or mission of the applicant organisation. This paper will describe work undertaken investigating the application of lean thinking to a continuous production environment, in this instance exemplified by the cement industry.

The cement industry is an ideal example of a continuous process industry and it will be used to demonstrate that the lean philosophy is applicable outside the realm of discrete manufacturing. There are numerous challenges facing the industry in today's competitive environments. One of the major challenges is its capability 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 production line is widely acknowledged in order to reduce the downtime rates, and satisfy high levels of market demand for their product.

The undertaken research proposes standard steps that can be carried out in lean transition. Hence, the research undertakes a novel step in integrating a modelling system of the production line with Taguchi Orthogonal Array which will investigate the different types of variability that can occur within cement production. The integrated method is 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 industry can be transformed from a traditional mass production operation into a lean enterprise.

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

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. 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. Use the Taguchi Orthogonal Array to help in improvement of the cement industry efficiency...

2 LITERATURE REVIEW

This section summarises the main research areas involved in the work described in this paper. It provides a brief explanation of key elements associated with lean engineering, including definition of waste, implementation and modelling. It also provides an overview of cement production and a description of the initial raw milling process which is used to illustrate the research throughout the rest of the paper.

2.1 Lean Engineering

The key element of the lean strategy is to develop a learning system that has the ability to identify and distinguish between the value added and non-value added activities (wastes). The seven main types of waste as defined by lean thinking are as follows:

1- **Overproducation**: 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).

2- **Transportation**: any unnecessary transfer or movements of components or materials is defined as transporting waste (Hicks, 2007).

3- **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).

4- **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 a symptom of hidden problems within the imperfect system. High levels of WIP are 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 with components, work-in-progress and finished product not being processed (Carreira, 2005)

5- **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).

6- **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).

7- **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 equipmentand 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).

Table 1 illustrates the wastes and non-value added activities which are associated with the cement industry.

TABLE 1
WASTES WITHIN THE CEMENT PRODUCTION.

2.1.1 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. Its implementation can generate superior operational and financial improvements within all systems. Though originating in, and being associated with, the manufacturing industries it 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) different organisations share
common characteristics which can be summarised as:.

a) **Inputs:** mean resources such as machinery, raw materials, capital, and people.
b) **Process**: become the second element; a proper sequence of actions and steps must be accomplished providing product or service that meets customer demands and
c) **Output:** Organisations are classified according to their outputs. The organisation that produces intangible products called service organisation such as health care, education, andinsurance companies. While the organisation that produces tangible items known as manufacturing organization.

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. There are numerous approaches of lean implementation. However the research described attempts to propose a general improvement path which can be used by all organisation types.

2.1.2 Modelling of Lean

In recent decades, 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 (Davis et al, 2007). 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). Fowler (2003) mentioned that a 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 a system.

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

Lean Wastes	The Cement production line wastes
Overproduction	Overproduction isclearly present within the cement manufacturing process resulting in very high levels of WIPbetween 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 from 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 indu tries with largest inventories and WIP. Non-standardisation an 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.

a) represents the actual activities and processes of the applicant organisation through using the real-world data,
b) captures the casual interrelationships between the organisation components,
c) able to identify specific wastes and problems that may occur within the organisation, and
d) able to validate the corrective actions through analyse different scenarios and comparing the obtained results with the expected or desired once.

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).

2.2 CEMENT PRODUCTION

The cement industry is one of the oldest industries in the world. The demand for cement has risen rapidly since the beginning of the 20th century to become the second most consumed substance after water (Karim et al, 2011). The industry is characterised by high levels of consumption of raw materials and energy with fuel accounting for 30-40% of the production costs.

The currently 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 typical and are another main criterion of a mass production system.

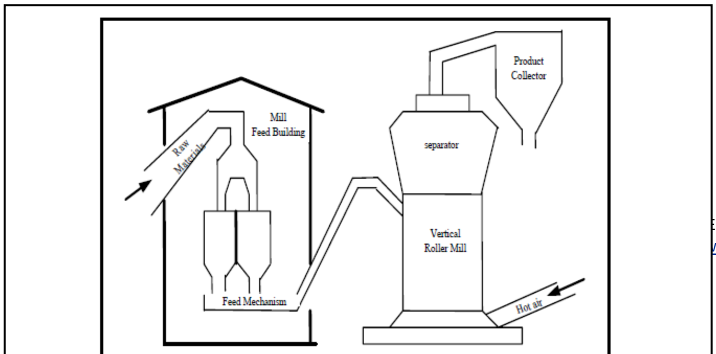
There are a number of methods for producing cement depending on the moisture content of the raw materials used. Mintus (Mintus, 2006) defines these as the wet, semi-wet, semi-dry and dry processes. Modern cement production typically uses the dry process as this is the most energy efficient method available. Therefore, this research has focussed on the dry process of cement production.

Briefly, the dry process can be summarised into three main production processes: dry raw milling process, dry thermo-chemical process, and finish grinding process. Dry raw milling is the initial stage in cement production and involves the mixing and preparation of the raw materials used prior to their entry into the cement kiln. The dry thermo-chemical process is the heart of cement production and consists of a long kiln where the feed meal is heated to produce clinker (the active ingredient of cement) which is then cooled prior to final processing.

Finish grinding is the final stage of production where the clinker is combined with other materials (e.g. gypsum) and ground in a ball mill to produce the final product.

For the purposes of this paper, the initial process of the dry process, dry raw milling, will be detailed in more depth and will be the process used to illustrate the research methodology and findings.

2.2.1 Dry raw milling process



Dry raw milling involves the mixing and preparation of the raw materials used prior to their entry into the cement kiln. Figure 1 shows the process and the five sub-processes of which it comprises. These are:

1- **Mill feed**: controls the supply of the blended raw materials to different milling machines within the raw milling site.

2- **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 they represent the most economical and reliable method, low operating and maintenance costs, and low environmental and safety risks.

3- **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 a separator, which located on the top of the mill unit. The fine particles will be separated and conveyed to product collector while the coarser particles are re-circulated to the table for regrinding (Simmons et al, 2005).

4- **Separator:** As mentioned above the reason for using the separator is to classify and return the oversize particles of the raw materials.

5- **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

Material property	Effect on performance / profitability
Moisture Content	Energy use and cycle time are proportional to the moisture content of the raw materials used. Materials with high moisture content will require increased time and energy spent during production. (Brundiek et al, 1997)
Grind-ability	Classified as Easy/Normal/Hard, material grind-ability directly affects the amount of time and energy required to process the raw materials and exerts a strong influence on the deterioration of production equipment. Hard to grind materials will cause increased wear and tear on equipment such as rollers, mill tables and grinding media. (flosberg, 1997)

Milling property	Effect on performance / profitability
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. It is also dependent on the fineness of the raw material feed. A high regrinding rate has negative effects on the productivity and production costs. The optimum recirculation rates for ordinary cement are in range of 10-30% of the whole feed materials. (Folsberg, 1997)
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 coarse particles. (Ito et al, 1997)
Mill pressure	The mill loading state is indicated by the differential pressure between inlet and outlet mill points. Overloading is indicated by very high differential pressure and leads to high levels of rejected. Therefore, the mill pressure should be maintained to an optimal level to avoid this outcome. However, the feeding process maybe blocked when the differential pressure reaches very low readings. The differential pressure is governed by the flow rates of air and feed materials. (Tamashige et al, 1991)

raw meal with the required chemical compositions. The homogenising process controls the raw meal's quality before fed into the kiln.

Table 2 shows some of the key properties of the raw milling sub-process and describes their effect on cement production. Reference sources from the literature review carried out are provided where relevant. In addition, some of the inherent properties of the raw materials used can have a major impact on the raw milling process. These are listed in Table 3.

TABLE 2
RAW MILLING PROCESS AND THEIR EFFECTS ON CEMENT PRODUCTION

TABLE 3
RAW MILLING PROCESS AND THEIR EFFECTS ON CEMENT PRODUCTION

Material property	Effect on performance / profitability
Fineness	Represented by the Blaine number, product fineness affects product quality, processing time, separator speed, and regrinding rates. Materials with higher Blaine number need the separator to run at higher speeds. (Touil et al, 2005)
Particle Size	Increased processing time is needed for grinding large particles/ Grinding and blending processes of large particles consume more energy and longer processing times. Therefore large chunks of raw materials should be crushed and pre-grinded into standard sizes. (Gordon, 2004)

Milling property	Effect on performance / profitability
Material flow rate	A high rate of feed meal into the process leads to a dramatic reduction in mixing speed which will increase the overall production cycle time(Palmer et al 1998)
Material bed thickness	An insufficient bed thickness of raw materials increases the production costs and results in high rollers wear rate. However, excessive bed depth minimises the compression force between layers and results in increased production costs. Accordingly, the maximum mill capacity is proportional to the diameters of the table and rollers and number of rollers used. (Gordon, 2004; Tamashige et al, 1991
Air flow rate	Air flow rate should be kept to the minimum value necessary for drying the raw materials and sweeping up fine particles. To minimise energy usage, the rate should be limited to that necessary for lifting the grinded materials to the separator. This also reduces separator wear rate. However, the productivity of grinding process is proportional to the air flow rate. (Roy, 2002; Ito et al, 1997; Brundiek et al, 1997)

3 Research method & results

The success and validity of any research critically depends on the research method which is used to collect, analyse, and interpret data. The undertaken research consists of six steps which are described in the following sections. Results obtained for the dry raw milling process are included with each step to explain and demonstrate the utility of the approach taken.

3.1 Step one: Data collection

The initial 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 implemented a mixed method of both quantitative and qualitative data including

Review of published literature (e.g. Bhatty et al, 2004; Kizilaslan et al 2003; Bond et al 2000) discussing the role of raw materials and production equipment properties on the product quality, cement production line productivity, and reliability of the machinery. The research identified different factors that are associated with or play an important role in the effectiveness of the cement production line. Those relevant to the dry raw milling process were described in section 2.2.1

1. Visits were arranged for data collection of the cement production line process from two selected sites:
    1.1 Ketton cement factory, Stamford, United Kingdom which hold 60% of the of the UK market share

    1.2 Suq-Alkhamis cement factory, Tripoli/Libya
2. 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.

3.2 Step two – Developing a simulation model

The main purpose of developing the model is to understand the process and to highlight the value and non-value activities that may occur within the cement production line and hence affect its efficiency. The Simul8 software package was selected as the experimental testing tool for converting the cement production line into a simulation model.

The model included the following working areas:

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

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

3- Cement grinding working area, which includes finish grinding workstation, packing house, and cement silos.

The simulation model produced had the following properties:

1) Run time: The simulation model runs for 43200 minutes (equivalent to one month (30 days) of real time operation).
2) Shift: The plant works on non-stop base, i.e. 24 hours per day.
3) Results collection period: The results will be collected after 43200 minutes.
4) 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.
5) Types of products: No variety of products, i.e. only one type of Portland cement is produced.
6) Probability distribution: Triangular distribution was chosen to be the probability distribution type within the undertaken research as it provides an acceptable trade-off between accuracy results (Khalil et al, 2008).

3.3 Step two – Developing a simulation model

The research identified several variables and factors, which control and govern the cement production line.

To investigate the nature of the interrelationship between these factors, brainstorming sessions were carried out with industry experts and led to the development of Cause-Effect matrices identifying non-relations, indirect-relations, and direct-relations between the variables. During the brainstorming sessions many creative ideas were generated and evaluated. This led to an agreed list of most effective variables, their interrelationships and their effects on production.

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 cause and effect matrices.

Table 4 illustrates the interrelationships between the identified variables for the dry raw milling process. For example;

D1 = direct interrelationship,

D0 = indirect interrelationship, and

I = absence of any interrelationships between the variables.

TABLE 4
RAW MILLING PROCESS CAUSE AND EFFECT MATRIX

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

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

3.4 Step four: Developing a connectivity matrix to minimise the number of variables.

It was not practical to carry out experiments including all variables that influence the performance of each process within the cement production line. Therefore, connectivity matrices were developed for each of the three main processes in order to identify the most critical and influential variables. This was achieved by removing all the non-direct relationships for the cause-effect matrices and then adding a column representing the summation of all remaining direct relationships for each factor. The factors with the highest totals of direct relationships were then identified as those key to the process. These key factors identified in the resultant connectivity matrix were then used in the development of the different simulation model experiments (see step 5). Only the variables that have the highest score of direct-relationships were used. To illustrate this step, the connectivity matrix produced for the dry raw milling process is shown in Table 5.

In terms of the dry raw milling process, the seven most influential factors (i.e. those with a direct interrelationship with four or more other factors) were identified using the connectivity matrix (highlighted in green in Table 5). These seven factors were then used in the design of experiments for the simulation model as described in the following section (step 5 of the method).

TABLE 5
CONNECTIVITY MATRIX FOR RAW MILLING PROCESS

Raw Milling Process Variables	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)		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 (cm³/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**	

3.5 Step five: Using Taguchi Orthogonal Array.

The Taguchi method for Design of Experiments (DoE) is a proven approach to assess the impact of variations to key parameters on a production process. It uses Orthogonal Arrays (OA) to organise the parameters and represent the levels of their variation. The Taguchi DoE is an efficient method for testing which factors most affect a production process with the minimal number of experiments required. It is therefore an ideal method to use in this research.

A L27 orthogonal array (suitable for range of 32 - 313 cases) was selected to be used in this work. Table 6 shows the seven factors used for the dry raw milling process and the three levels of variability used in the DoE and Table 7 shows the Orthogonal Array that this produced.

TABLE 6
DRY RAW MILLING PROCESS VARIABLE LEVELS

Raw Milling Process Factors	Level 1	Level 2	Level 3
Air flow rate (cm3/min)	7100	7200	7300
Recirculation rate (% of feeding rate)	15	20	25
Material moisture content (% of weight)	12	16	20
Material grind-ability	Easy	Normal	Hard
Material bed depth (cm)	4	5	6
Product fineness (cm3/g)	3900	3950	4000
Separator speed (rpm)	60	65	75

TABLE 7
TAGUCHI L 27 OA-THERMO-CHEMICAL PROCESS

Air flow Rate (c^{3}m/min)	*Recirculation Rate (%weight)*	Material Moisture	Material Grindability	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

3.6 Step six: Performance measurements identification

A successful implementation of lean 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 were chosen to be the performance measures for the cement industry and are described in the following sections.

These parameters were chosen because any improvement and enhancement within these three parameters gives an immediate positive feedback which is easily recognised and reflects on the whole production line. Reduction of the cycle time and improvement of the throughput and machine utilisation can be translated into increased customer satisfaction and overall performance (Lynes et al, 1994).

3.6.1 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 overall performance by increasing customer satisfaction, reducing production costs, and providing key competitive advantages. The reduction of the cycle time can be o btained by eliminating or minimising all kinds of wastes and non-value added activities within the given system (Jones et al, 1999)

3.6.2 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, eliminating or minimising wastes is essential in order to increase the equipment utilisation (Jambekar, 2000). Lee et al (1994) have identified the equipment utilisation as:

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

where

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

$Unused\ Time = PMT + BT$,

$BT = Breakdown\ Time$ (min).

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

Therefore the percentages of machine utilisationcan be determined as

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

3.6.3 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:

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

Where

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

$BT = Breakdown\ Time$ (min).

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

4 Experimental results – Implementing lean improvement

The literature review and data collection carried out had shown that the cement industry is characterised by high levels of WIP. As highlighted in section 2.1, many problems and root causes of performance insufficiencies can be shrouded and buried behind high levels of WIP. Therefore, the initial priority of implementing Lean within the cement industry is to eliminate or minimise the WIP levels.

One of the main reasons of high WIP levels is the non-optimised batch size. To examine the impact of lean improvements on cement production, all workstation capacities were reduced by 10% in order to minimise the WIP levels. Experiment were devised using the reduced WIP figures and the simulation was used to examine the effects of this lean change on the overall cement production process in terms of the three performance measures highlighted.

The WIP reduction experiments undertaken demonstrated the potential benefits possible applying lean principles in cement. Figure 2 to Figure 4 illustrate the improvement to the three identified performance measures (throughput, machine utilisation and cycle time) before and after reducing the WIP within the raw milling process for all of the designed experiments. It is clearly evident that the throughput, machine utilisation and cycle time are improved as a result of WIP reduction.

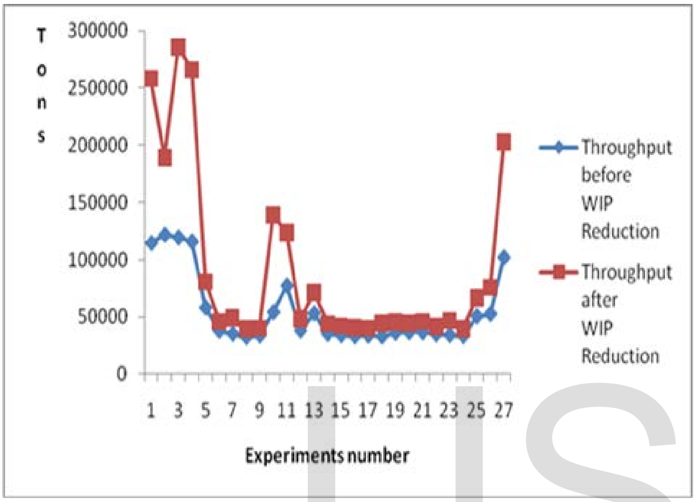


FIGURE 2
THROUGHPUT BEFORE AND AFTER WIP REDUCTION

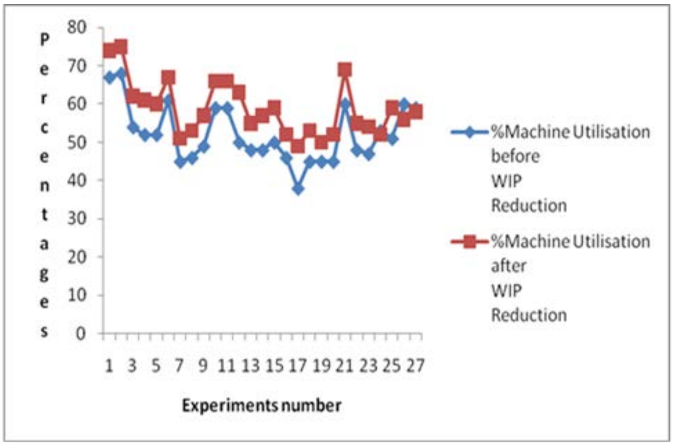


FIGURE 3
% MACHINE UTILISATION BEFORE AND AFTER WIP REDUCTION

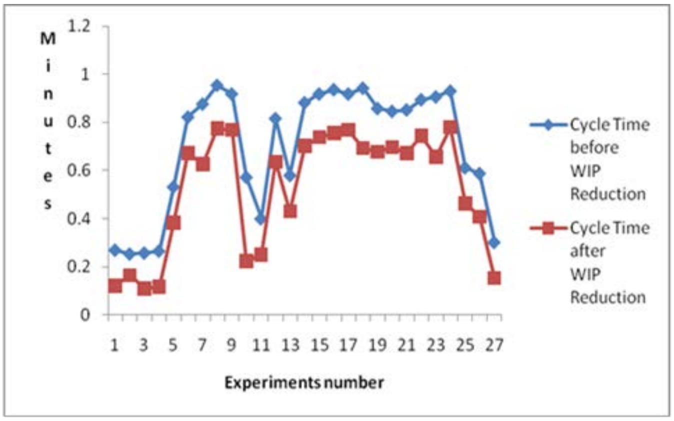


FIGURE 4
CYCLE TIME BEFORE AND AFTER WIP REDUCTION

Similar results were found for the effects of reducing WIP for the rest of the cement production line clearly demonstrating the potential efficiency gains that could be made by implementing lean in the cement industry.

5 CONCLUSIONS

The research succeeded in conveying the message to the industry stakeholders that the lean philosophy is not limited to specific organisations; however process industries and different organisations can reward amazing results through adopting lean thinking.

The research used cement production, a typical example of a continuous process industry, where mass production is currently adopted using inflexible and expensive machines to produce, transport, and accumulate large amounts of materials within each working area. Results from the simulated experiments carried out showed how lean changes could produce significant positive benefits to key performance measures and were validated by industry experts.

The research has proposed 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 is the combination of the simulation model with the Taguchi Orthogonal Array with the aim of improving the cement production line's efficiency.

REFERENCES

[1] Ahlstrom, P., 2004, Lean service operations: translating lean production principles to service operations, Journal of Services Technology and Management, vol. 5, no. 5-6, pp.545-564.

[2] Banks, J., 1999, Discrete Events Simulation, Proceedings of the 1999 Winter Simulation Conference, pp. 7-13

[3] Bhatty, J., Miller, F.M. & Kosmatka, S., 2004, Innovations in Portland Cement Manufacturing, Portland Cement Association, ISBN 978-0893122348.

[4] Bicheno, J., 2000, The Lean Tool Box, 2nd edition, PICSIE Books, Buckingham, England, pp.63-64

[5] Bond, J. E., Coursaux, R., Worthington, R. L., 2000, Blending systems and control technologies for cement raw materials, In IEEE Industry Applications Magazine, vol. November/December 2000, pp. 49-59.

[6] Braiden, B.W., and Morrison, K.R., 1996, Lean manufacturing optimization of automotive motor compartment system, Proceedings of the 19th International Conference on Computers and Industrial Engineering, vol.31, no.1-2, pp. 99-102.

[7] Browning, T.R., 1998, Use of Dependency Structure Matrices for product Development Cycle Time Reduction, Proceedings of the Fifth ISPE international Conference on Concurrent Engineering: Research and Applications, July-15-17, pp.1-8.

[8] Carley, K. M., 2002, Computational organizational science and organizational engineering, Journal of Simulation Modelling Practice and Theory, vol.10, no.5-7, pp. 253-269.

[9] Carreira, B., 2005, Lean Manufacturing that works: powerfull tools for dramatically reducing waste and miximizing profits, 2nd edition, AMACOM, New York, USA, pp. 49-61.

[10] Das, K. B., 1987, Cement Industry of India, 1st edition, Lohia Composing Agency Sunil Printers, New Delhi, India, pp.35-36.

[11] Davis, J. P., Eisenhardt, K. M., and Bingham, C. B., 2007, Developing theory through simulation methods, Journal of Academy of Management Review, vol. 32, no. 2, pp. 480–499

[12] Dennis, S., King, B., Hind, M., and Robinson. S., 2000, Applications of business process simulation and lean techniques in British telecommunications plc, Proceedings of the 2000 Winter Simulation Conference, pp. 2015-2021.

[13] Fowler, A., 2003, Systems modelling, simulation, and the dynamics of strategy, Journal of Business Research, vol. 56, no. 2, pp.135-144.

[14] Harrison, A., 1995, Themes for facilitating material flow in manufacturing systems, International Journal of Physical Distribution and Logistics Management, vol.25, no.10, pp: 3-25.

[15] Hicks, B.J., 2007, Lean information management: Understanding and eliminating waste, International Journal of Information Management, vol. 27, no. 4, pp. 233–249.

[16] Hopp, J. W., Spearman, M. L., 2001, Factory Physics, 2nd edition, Irwin, New York, USA

[17] Karim M. R., Zain M. F. M., Jamil M., Lai F. C., 2011, Significance of Waste Materials in Sustainable Concrete and SustainableDevelopment, International Conference on Biotechnology and Environment Management IPCBEE vol.18 IACSIT Press, Singapore

[18] Kempton, J., 2006, Can lean thinking apply to the repair and refurbishment of properties in the registered social landlord sector?, Structural Survey journal, vol. 24, no. 3, pp. 201-211

[19] Khalil, R.A., Stockton, D.J. and Fresco, J.A., 2008, Predicting the effects of common levels of variability on flow processing systems, International Journal of Computer Integrated Manufacturing, vol.21, no.3, pp.325-336.

[20] Kizilaslan, K., Ertugrul, S., Kural, A., and Ozsoy, C., 2003, A Comparative Study on Modelling of a Raw Material Blending Process in Cement Industry Using Conventional and Intelligent Techniques, Control Applications, 2003. CCA2003. Proceedings of 2003 IEEE Conference, vol. 1, no. 1, pp. 736-741.

[21] Law, A. M., 2005, How to build valid and credible simulation models, IEEE Proceedings of the 37th Winter conference on simulation, pp. 24- 32.

[22] Lee, S.M., and Schniederjans, M.J., 1994, Operations Management, 1st edition, Houghton Mifflin Company, New Jersey, USA, pp. 191-192

[23] Liker, J.K., 2004, The Toyota way: 14 management principles from the world's greatest manufacturing, 1st edition, McGraw-Hill, New York, NY, USA, pp. 29 and 35-41 and 140-144.

[24] Lynes, K., and Miltenburg, J., 1994, The application of an open queuing network to the analysis of cycle time, variability, throughput, inventory and cost in the batch production system of a microelectronics manufacturer, International journal of production economics, vol. 37, no. 2-3, pp. 189-203

[25] Mintus, F., Hamel, S., Krumm, W., 2006, Wet process rotary cement kilns: modeling and simulation, Clean Technologies and Environmental Policy, 18, 112-122.

[26] Neely, A., Mills, J., Platts, K., Richards, H., Gregory, M., Bourne, M., and Kennerley, M., 2000, Performance measurement system design: developing and testing a process-based approach, International Journal of Operations and Production Management, vol.20, no.10, pp. 1119-1145.

[27] Persoon, T.J., Zaleski, S., and Frerichs, J., 2006, Improving Preanalytic Processes Using the Principles of Lean Production (Toyota Production System), American Journal of Society for Clinical Pathology, vol.2006, no. 125, pp.16-25.

[28] Robinson, S., and Bhatia, V., 1995, Secrets of successful simulation projects, IEEE Proceedings of the 27th conference on Winter simulation, pp. 61 – 67.

[29] Wang, Q., and Chatwin, C.R., 2005, Key issues and developments in modelling and simulation-based methodologies for manufacturing systems analysis, design and performance evaluation, The International Journal of Advanced Manufacturing Technology, vol. 25, no. 11-12, pp. 1254-1265.

[30] J.S. Bridle, "Probabilistic Interpretation of Feedforward Classification Network Outputs, with Relationships to Statistical Pattern Recognition," *Neurocomputing – Algorithms, Architectures and Applications,* F. Fogelman-Soulie and J. Herault, eds., NATO ASI Series F68, Berlin: Springer-Verlag, pp. 227-236, 1989. (Book style with paper title and editor)

[31] W.-K. Chen, *Linear Networks and Systems.* Belmont, Calif.: Wadsworth, pp. 123-135, 1993. (Book style)

[32] H. Poor, "A Hypertext History of Multiuser Dimensions," *MUD History,* http://www.ccs.neu.edu/home/pb/mud-history.html. 1986. (URL link *include year)

[33] K. Elissa, "An Overview of Decision Theory," unpublished. (Unplublished manuscript)

[34] R. Nicole, "The Last Word on Decision Theory," *J. Computer Vision,* submitted for publication. (Pending publication)

[35] C. J. Kaufman, Rocky Mountain Research Laboratories, Boulder, Colo., personal communication, 1992. (Personal communication)

[36] D.S. Coming and O.G. Staadt, "Velocity-Aligned Discrete Oriented Polytopes for Dynamic Collision Detection," *IEEE Trans. Visualization and Computer Graphics*, vol. 14, no. 1, pp. 1-12, Jan/Feb 2008, doi:10.1109/TVCG.2007.70405. (IEEE Transactions)

[37] S.P. Bingulac, "On the Compatibility of Adaptive Controllers," *Proc. Fourth Ann. Allerton Conf. Circuits and Systems Theory*, pp. 8-16, 1994. (Conference proceedings)

[38] H. Goto, Y. Hasegawa, and M. Tanaka, "Efficient Scheduling Focusing on the Duality of MPL Representation," *Proc. IEEE Symp. Computational Intelligence in Scheduling (SCIS '07)*, pp. 57-64, Apr. 2007, doi:10.1109/SCIS.2007.367670**.** (Conference proceedings)

[39] J. Williams, "Narrow-Band Analyzer," PhD dissertation, Dept. of Electrical Eng., Harvard Univ., Cambridge, Mass., 1993. (Thesis or dissertation)

[40] E.E. Reber, R.L. Michell, and C.J. Carter, "Oxygen Absorption in the Earth's Atmosphere," Technical Report TR-0200 (420-46)-3, Aerospace Corp., Los Angeles, Calif., Nov. 1988. (Technical report with report number)

[41] L. Hubert and P. Arabie, "Comparing Partitions," *J. Classification,* vol. 2, no. 4, pp. 193-218, Apr. 1985. (Journal or magazine citation)

[42] R.J. Vidmar, "On the Use of Atmospheric Plasmas as Electromagnetic Reflectors," *IEEE Trans. Plasma Science*, vol. 21, no. 3, pp. 876-880, available at http://www.halcyon.com/pub/journals/21ps03-vidmar, Aug. 1992. (URL for Transaction, journal, or magzine)

[43] J.M.P. Martinez, R.B. Llavori, M.J.A. Cabo, and T.B. Pedersen, "Integrating Data Warehouses with Web Data: A Survey," *IEEE Trans. Knowledge and Data Eng.*, preprint, 21 Dec. 2007, doi:10.1109/TKDE.2007.190746.(PrePrint)