PRODUCTIVITY IMPROVEMENTS OF QUARRY PROCESS BY IDENTIFYING LEAN WASTES

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DECLARATION

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ABSTRACT

The Sri Lankan Central Bank Annual Report 2013 revealed that, the construction industry contribution to GDP has reached 8.7% in year 2012 with continual growth from 2003. It further says that, more public investments in the highway sector contributed to sustaining the growth momentum in the construction industry. Hence construction has automatically become one of the major energy consuming industries in the country. In that regard, the Asphalt concrete production process is at the top level of energy consumption due to the higher amount of energy used to raise the temperature of raw materials to a high mixing temperature of around 150 C.

Key findings of a research done on the Asphalt Coating Plant in Scotland, reveals that it is economical to have daily production throughout of at least 100 tones and 1% moisture increment of aggregate, increases the fuel consumption by 0.7 liter/tone (Gillespie, 2012). The above research doesn't cover the stone quarrying process which provides the aggregates for asphalt production. The research done by Rylander (2013) on the quarrying process has contributed to find lean wastes happening in the raw material supplying process from quarry to crusher.

Controlling aggregate production costs are a significant problem in the quarrying process due to high competition in the industry. The production cost of aggregates is severely affected by the selected crushing circuit. In this thesis, the study was carried out based on two different crushing circuits to find a more productive crushing circuit in the quarrying process. The lean principles were applied to identify the lean wastes over production, waiting, transportation, non-value-added processing, excess inventory, defects, excess motion and underutilized people in two crushing processes. The identified wastes of each circuit were analyzed compared to the other circuit. This study was limited to horizontal flow crushing.

The analyzed results show that cellular manufacturing with intermediate stockpile increases the availability of the system by minimizing the waiting. At two-stage crushing circuit uses less manpower, machinery and electricity power than a three-stage crushing circuit since two-stage crushing minimizes the waste over conveyance, over motion and over utilization of people. Finally, the study recommends that by selecting the circuit, two-stage crushing with cellular manufacturing can increase the productivity of the system.

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ABBREVIATIONS

JIT - Just In Time

JIC - Just In Case

VSM - Value Stream Mapping

WIP - Work in Process

CSS - Closed Side Setting

PO - Purchase Order

MRF - Material Requisition Form

GRN - Goods Received Note

CHAPTER 1

1.0 Introduction

1.1 Background

The Sri Lankan construction industry is expanding in the face of the country's post-conflict scenario. It has generated a significant demand for power, roads, ports, water supply, sanitation, tourism, housing, and reconstruction occupies an important position in the economy as in any developing country. In 2013 construction contributed about 10% to the country's Gross Domestic Product (GDP) (Central Bank Annual Report, 2013). The Government of Sri Lanka (GOSL) is targeting an annual economic growth rate of 6-8 percent over the next five years, and infrastructure development is of paramount importance in supporting these growth targets (World Bank, 2014).

Currently, there is a strong focus on road construction and maintenance given its importance for employment growth and new business development in Sri Lanka. Road development in the country, which was neglected during the war, has been given prominence. It has become vital further investment in road networks, which has become a major determinant of new investments in the country. The road infrastructure was invigorated through rehabilitation and new construction, to meet the rapid increase in traffic, particularly seen during the last few years with the rapid expansion of economic activities. The National Road Master Plan (2007-2017) was drawn up to meet the challenges encountered by the country's road sector and to meet the growing demand for road infrastructure (Central Bank Annual Report, 2013).

In the construction industry, the quarry operations produce different sizes of aggregate, for all scales of road and building constructions. Road construction uses aggregates on mass scale for producing asphalt concrete and an aggregate base course preparation. Therefore quarry operations have become a very vital sector in the construction industry with large scale highway construction. A quarry operation in general is a complex process involving a large range of machinery and plant and high operating and maintenance costs. Hence, the quarry management team often face the challenge of choosing the right fleet of machinery and optimizing at synchronized production process. The quarry management's right decision at both strategic and tactical level contributes greatly to controlling the production costs and optimizing the production process of the quarry.

1.2 Problem Definition

Any construction firm always operates in a competitive environment and has to develop new methods to improve organizational effectiveness in terms of construction. The traditional method of selling price and adding the profit to the production cost is no more valid in quarry industry now, because the selling price of aggregates has become fixed with high competition in the industry. Customer is more powerful than ever before. They have a wealth of choices and unprecedented access to information and they demand excellent quality at a reasonable price.

Old equation of price

$$\text{Cost} + \text{Profit} = \text{Price}$$

New equation of price

$$\text{Price}(\text{Fixed or Falling}) - \text{Cost} = \text{Profit}$$

Thus in a competitive environment, the specific method to increase profit is to reduce cost. Reducing the cost of production goes parallel with productivity improvement of the process. "Lean" is one productivity improving principles developed by Toyota. The lean concept is based on elimination of wastes that happens in any process. Although lean is rooted in the manufacturing industry, currently it has become universal application. The challenge faced by any organization is to translate, tailor and apply lean principles in to their particular situation.

A recent research done by Rylander and Axelsson (2013) on quarry productivity by applying lean principles has identified the wastes of overproduction, waiting, over processing, over inventory / buffer and unnecessary movements in the synchronized process areas loading, transporting and buffer /inventory handling. The researcher has shown the impact of the above waste by the improved process. But the research study has been limited to a single domain due to the limited availability of data and information. A broader study to find a further potential improvement area in quarry operation, by considering different domains with similar need will be a good future study.

This research is mainly focused on finding the potential improvement area of the quarry process by comparing two different domains (crusher layouts). In addition this action research discusses methods to increase the productivity of quarry operations. Although the company has a well-established system for monitoring and controlling the productivity of each process, the initial study done in this research for two quarry operations have identified that, the production cost is varied with different production process circuits (layouts)

1.3 Research Objectives

- To identify lean wastes that can happen in crusher operations with different crusher circuits (layouts).
- To assess the impact of identified lean wastes in quarry/crusher operations with different crusher circuits (layouts).
- To identify methods of eliminating lean wastes in crusher operations.

1.4 Significance of the study

The construction industry is playing a major role in the development of the country, since the necessary infrastructure must be developed to meet the unlimited demands of the population. Increasing the productivity of the construction industry will reduce waste and costs. The rapid expansion of construction has created a highly competitive environment among the construction organizations. Therefore traditional methods and strategies adopted by the construction organizations would not be effective for survival and maintenance of the competitive edge in the long run.

Since new challenges emerge in the industry on a daily basis, construction organizations should explore new business strategies and innovative methods. Now it has become an essential requirement for the success of the business to monitor the cost of production and identify drawbacks in the existing system. Continuous monitoring and improving of existing systems in construction is supported by the rapid development of information technology.

This research provides information to the industry, about the impact on productivity of waste caused by waiting, inventory handling, over transport and over motion in different crusher layouts. Since these wastes are not directly identified through cost monitoring, this research study will help to find and initiate a new strategy to reduce waste in the quarry process. Finally, the study will improve awareness of the impact of the above waste on the quarry process and lead to new strategies to increase productivity by reducing identified wastes.

1.5 Methodology

The researcher used the action research method to achieve the above objectives. Two plant complexes comprising quarry, crusher and asphalt plant were selected for the research. Crusher operations and asphalt plant operations are not conducted in sequence or in parallel. Therefore the only the quarry operation with crusher plant operation was selected for the study. In a quarry operation, blasting works are not in parallel operation for safety reasons. Thus blasting processes were excluded from the study.

The methodology consisted of three steps.

1. A detailed literature review was done to study previous related research done by Sri Lankan and international researchers for identifying the potential improvement in construction productivity and quarry/plant productivity.

2. A work study was conducted on the raw material supplying process of two plants to identify the lean waste that can be happen in the process. Necessary precautions were taken to eliminate that waste. After the completion of the supply process improvement, production data was collected over several months.

3. The collected production data and observation data were analyzed based on machinery, manpower, and power usage for two crushing circuits to find the lean waste resulting from in the process.

1.6 Limitations of the research

Only two crushing layouts were selected for the study. Layouts with vertical material flow need to be analyzed separately because its structural cost is high although consumes less energy.

1.7 Main Findings

The crushing circuits can be divided into cells by introducing intermediate coarse material stockpiles. The intermediate stockpile provides improved overall system utilization by de-linking the primary and subsequent crushing operations. Also, it enables continuing operations of secondary crushing while the primary crusher becomes inoperative.

Two-stage crushing is more efficient than three-stage crushing. In latter more lean waste happen like over conveyance, over motion and over consumed power than the former.

1.8 Component of the Report

Chapter 01 – Introduction

This chapter describes the background of the construction industry in Sri Lanka, defines the problem, sets out the objectives, and basic guidelines of the research.

Chapter 02 – The Literature Review

The history and background of lean manufacturing, importance of lean manufacturing in industry, general principles and lean transformation, lean in the construction industry, and the recommendations of previous researchers are discussed in depth in this chapter.

Chapter 03 – Research Methodology

This chapter deals with details of the quarry and crusher operation, cellular manufacturing, framework of the research, and the method of data collection and data analysis.

Chapter 04 – Analysis and Discussion

This chapter covers the calculations and the analyzed data. The results of the analyzed data are given in graphical form.

Chapter 05 – Conclusions and Recommendations

This final chapter covers the research findings and recommendations for improving the existing crusher plants and for the implementing the proposed plant layout.

CHAPTER 2

2.0 The Literature Review

2.1 General

The use of the term "lean", in a manufacturing or production environment, describes a philosophy that incorporates a collection of tools and techniques into the production processes to optimize time, human resources, assets, and productivity, while improving the quality level of products and services for their customers. It means creating more values for customers with fewer resources. Lean thinking in action is the continuous identification and elimination of waste from an organization's process, leaving only value-added activities in the value stream, Rother and Shook, cited in (Xia and Sun 2013).

2.2 History and Background of Lean Manufacturing

The avoidance of waste has a long history. In fact many of the concepts now seen as key to lean were discovered over the years in research into waste reduction. Initially lean thinking was used in Arsenal in Venice in the 1450s, but Henry Ford the founder of the Ford Motor Company was first to truly integrate the concept into an entire production process at the Highland Park manufacturing plant, in 1913.

Ford synthesized interchangeable parts with moving conveyers and flow production. He aligned the manufacturing line in a process sequence using special purpose machines and assembled the components going into the vehicle within a few minutes and delivery perfectly fitting components directly online. Ford took all the elements of the manufacturing system, people, machines, tooling, and products and arranged them in a continuous system for manufacturing the Model T automobile. Ford was quick to become one of the world's richest men and put the world on wheels. He is considered by many to be the first practitioner of Just In Time (JIT) and Lean Manufacturing.

When the world began to change the Ford system began to breakdown but Henry Ford refused to change the system. In the 1920s labour unions conflicted with the Ford system and product propagation also put a strain on the Ford system. Annual model changes, multiple colours, and options did not fit well in the Ford factories. The problem of the Ford system was not the flow but his inability to provide variety.

Toyota's development of ideas that later developed into “lean” may have started at the turn of the 20th century with Sakichi Toyoda, in a textile factory with looms that stopped themselves when a thread broke. Toyota’s journey with JIT may have started back in 1934 when it moved from textiles to produce its first car. After World War II Kiichiro Toyoda founder of the Toyota Motor Corporation and Taiichi Ohno made a series of simple innovations that might make it possible to provide continuity in the process flow and a wide variety in product offerings. They revisited Ford’s original thinking, and invented the Toyota Production System.

In the Toyota Production System they re-sized machines in line with the actual volume needed, introducing mistake proofing to ensure quality, lining the machine in a process sequence, and planned a quick change over to processing small volume of many part numbers. All these made it possible to obtain low cost, high variants, high quality, and very rapid throughput time to respond to changing customer desire. The continuing success of Toyota over the past decade created an enormous demand for generating knowledge about lean thinking.

2.3 Importance of the Lean Manufacturing Process

Any production or manufacturing process can greatly benefits from having in place lean processes through which to handle the products or services. Because lean is used to continuously improve any process through the elimination of waste. It is important to reduce the levels of waste that are involved in any production process to reach better levels of productivity and efficiency. Waste can be described as all those activities that produce costs direct or indirect, and use time resources or require storage but do not add value or progress to the product. The seven types of waste that originated in lean manufacturing are known as “muda”. It was originally developed by Toyota’s chief engineer Taiichi Ohno as the core of the Toyota Production System. The seven wastes categorized by Taiichi Ohno within the Toyota Production system are;

Waiting - Time that is, when work in process is waiting for the next step in production. In other word waste from waiting is any idle time produced when two interdependent processes are not completely synchronized. Much of production waiting time is tied up in waiting for the next operation; this is usually because the material floor is poor, production runs are too long, and distance between workcentres are wide.

Transport - Unnecessary movement of raw materials, work in process or finished goods. Material handlers must be used to transport the materials, resulting in another organizational cost that adds no customer value.

Overproduction - Overproduction is manufacturing an item before it is actually required or producing more than what is required. Overproduction manufacturing is referred to as “Just In Case”. This creates excessive lead times, resulting in high storage costs, and making it difficult to detect defects.

Over processing -Over processing is more processing than what is needed to produce what the customer requires. Over processing is caused by

- Absence of standardization of best techniques.
- Unclear specifications/ quality acceptance standards.

Inventory - Product (raw materials, work-in-process, or finished goods) quantities that exceed immediate need or any supply in excess of what is required to deliver products in a Just In Time manner. It increases lead time, consumes productive floor space and also the quality of inventory can deteriorate over a period of time.

Motion - Any movement of either people or machines, which does not add value to the product or service. Wasted human motion is related to workplace ergonomics. Productivity suffers when there is unnecessary walking, reaching or twisting. Quality suffers when the worker has to strain to process or check the work piece because of reaching, twisting or poor environmental condition. The waste of machine motion also exists as when, for example, the work piece and a spot welding machine are unnecessarily far from each another. (Dennis, 2007)

Defects - Wastes from defects involves production that is scrap or requires rework. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost. Defects also include cost of goods returned by customers or recall campaigns. Employee involvement and continuous process improvement offer a huge opportunity to reduce defects.

Waste sources are all related to each other and getting rid of one source of waste can lead to either elimination or reduction of others. Therefore, the elimination of waste is an essential for the any industry to improve efficiency and effectiveness of total productivity.

2.4 General Principles of Lean Manufacturing

Womack and Jones, cited in Hines (2009), identified five principles of Lean Production, for implementing the concept in different industrial branches. As described by Hines (2009), the five principles of lean are; “precisely **specify value** by specific product, identify the **value stream** for each product, make value **flow** without interruptions, let the customer **pull** value from the producer, and pursue **perfection**”. This statement leads to the five principles of lean thinking: Value, Value Stream, Flow, Pull and Perfection. They defined each of these principles in more detail as follows:-

Value

Value is defined by the customer. It is only meaningful when expressed in terms of a specific product which meets the customers’ need at a specific price at a specific time. By clearly defining value for a specific product or service from the customer’s perspective, all non-value activities or waste can be targeted for removal. In identifying customers’ value, it is important to answer the following questions: what do customers want, when and how do they want it, what combination of features, capabilities, availability and price are preferred by them.

Value stream analysis

The value stream is all the steps and processes required to bring a specific product from beginning to end into the hands of the customer. This represents the end-to-end process that delivers value to the customer. The value stream is not limited by boundaries between companies; this is the reason for striving to integrate suppliers, manufacturers, distributors and even retailers in the effort to recognize and analyze the value stream. Value stream analysis will almost always shows that three types of actions are occurring along the value stream.

- Those that add value,
- Those that do not add value but cannot be currently avoided, and
- Those that do not add value and should therefore be eliminated.

Continuous flow

Flow recognizes the process so that the product moves smoothly through the value creating steps. It should flow steadily and without interruption from one value adding or supporting activity to the next. Continuous flow is defined as the "progressive achievement of tasks along the value stream so that a product proceeds from design to launch, order to delivery and raw materials into the hands of the customer with no stoppages, scrap or backflows". Ways to raise flow include enabling quick changes of tools in manufacturing, as well as rightsizing machines and locating sequential steps adjacent to one another.

Pull

Pull is about understanding customer demand for service and then creating a process to respond to this such that only what the customer wants is produced and when he wants it. Companies should not push their products to customers, but rather let them pull. Value and link the whole production chain in such a way that materials are not released and activities are not done until they are needed. This is in contrast with pushing products through a system, which is unresponsive to the customer and results in unnecessary inventory buildup.

Perfection

Perfection is defined again by Womack and Jones, cited in Ciarniene and Vienazindiene (2012), as the "complete elimination of waste so that all activities along a value stream create value." Perfection requires constant striving to meet customer needs and improve one's process with zero defects. Creating flow and pull starts with radically reorganizing individual process steps, but the gains become truly significant as all the steps are linked together. As this happens more and more layers of waste become visible and the process continues towards the theoretical end point of perfection, where every asset and every action adds value for the end customer. It is the conviction that improvement efforts are never finished, and it is consistency that keeps the discipline for improvement in place (Kaizen).

2.5 Lean Transformation Process

Lean Transformation begins with a company's ability to take an honest look at its productivity, profitability, and culture. The biggest piece in the lean transformation process is the change from traditional thinking to transformational thinking. Based on Duque & Cadavid (2007), Transformation of Lean Philosophy and Principles can be described as a set of actions and processes starting from planning the change, defining the success factors and finishing by implementation and measuring the progress.

2.5.1 Planning the change

The first step in lean transformation is planning the change. Three things should be done at the very beginning.

i. Define the need for change

   Before leaping as usual to lean transformation, it is essential to understand the motivation for a lean transformation effort. It involves a complete overhaul in the way that managers and workers view the company and their role in it. And this should provide guidance and clarity to everybody in the company.

ii. Enlist top management commitment and support

   If the employees don't believe in a real commitment from upper management, nothing will happen. There should be someone in the company who is willing and qualified to take a position of leadership wherein they are personally responsible for the lean transformation process. Their involvement and support should be not only verbal but also factual.

iii. Identify target areas and propagation strategy

   A plan should be created, indicating which processes and production lines will be transformed to lean, in what sequence and time frame. This plan should also address which lines are going to go first, and also how the people from that line are going to contribute in the propagation of lean concepts through training and coaching for subsequent product lines.

2.5.2 Success factors

In the lean implementation process most companies do not succeed as they should, and there can be practical difficulties in applying these principles. Many of the reasons can be traced back to lean initiatives or an organizational practice of lean initiatives. This includes categories and elements of each initiative, and organizational challenges that include all obstacles in the path of the lean transformation process. To successfully overcome these challengers, some factors must pertain to the implementation process. But certain success factors are suggested by different authors and researchers and there is actually no consensus on what the main success factors are in lean implementation. According to the framework developed by Liker, cited in Duque and Cadavid (2007) there are four key factors for success in the implementation of lean effort.

i. Preparation and motivation of people

   Ultimately in all organizations lean implementation performance comes down to human behaviour, and there are always two aspects to achieving high performance: one is preparation and other is motivation. It includes intense communication, clarification of expectations, emphasizing the need for change and, essentially letting people know what's ahead. Therefore widespread orientation is required to prepare and motivate people and to make them understand the need to switch to lean manufacturing.

ii. Roles in the change process

   For effective implementation of the lean effort, both employees and managers have a role to play in all aspects of their job. It need strong top management leadership and as well support from other levels of management. Also experts have to act as coaches and the other functional areas require roles that need to be filled for the success of lean implementation.

iii. Methodologies for change

   All technical tools are needed like the use of model lines, the right sizing of machines, quick and visible improvements, orientation to action, working in focused teams and changing physical line layout.

iv. Environment for change

   The transition from a traditional to lean environment requires environmental change in the organization rather than changing the manufacturing or technical issues. There is less consistency across cases in the "Environment for Change" needed for implementing lean. Some factors of the environment change are job security (no one can lose their job because of lean), an explicit set of guiding principles, creating a safe environment for experimentation, and building trust (mutual trust between workers and management and also amongst different work teams).

2.5.3 Lean Tools and Techniques

There are many tools and techniques that can support to lean principles when implementing lean production processes. Some of the critical ones are as follows:-

- Value Stream Mapping – Mapping value stream using ideas and techniques such as Value Stream Mapping (VSM) or simple Flow Chart diagrams are very powerful ways to identify and highlight the wasteful steps in the processes. This allows to create future state maps and create action plans to simplify work and drive improvements.
- 5Ss constitute - one of the basic building blocks of Lean Manufacturing. They offer a basic housekeeping discipline for the shop floor and the office. Creation of standardized work is a primary reason for using the 5Ss method. It includes the five steps of Sort, Straighten, Shine, Standardize, and Sustain.
- Kaizen - Kaizen is a generic Japanese word for improvement or "making things better." Kaizen is all about continuously improving every process in a company. This can be done through ongoing continual improvement or through a dedicated Kaizen Blitz designed to make a rapid improvement to a specific area of a business.
- One Piece Flow - This concept emphasizes reducing the batch size in order to eliminate system constraints. It is a methodology by which a product or information is produced by moving at a consistent pace from one value-added processing step to the next with no delays in between.
- Cellular Manufacturing - Cellular manufacturing is an approach in which all equipment and workstations are arranged based on a group of different processes located in close proximity to manufacture a group of similar products. The primary purpose of cellular manufacturing is to reduce cycle time and inventories to meet market response times
- Mistake Proofing / Poka Yoke - A methodology that prevents an operator from making an error by incorporating preventive in-built responsiveness within the design of product or production process.

2.5.4 Implementation

According to Karlsson and Ahlstrom, cited in Vienazindiene and Ciarniene (2013), implementation of lean philosophy can be described as a set of actions and processes including planning the change, defining the success factors, lean tools and techniques, and finishing by implementation and measuring progress. These implementation activities should lead to improvement along five dimensions.

i. Elimination of waste

   Waste is everything that does not add value to the product, like inventories, machine setups machine downtime, movement of parts and scrap.

ii. Continuous improvement

   Continuous improvement means incremental improvement of products or process over time and it is consistency in maintaining the discipline for improvement in place.

iii. Continuous flow and pull driven system

   Lean systems are characterized by smoother flow products through the line, abandoning the batch mentality and adapting to accept the pull of each process.

iv. Multifunctional teams

   These are groups formed of people with varying skill-sets typically across different sections to achieve goals. Using multifunctional teams can be of great benefit to most companies especially when they work with complex issues that require expertise in numerous backgrounds.

v. Information Systems

   The company should have a better information system to enable employees to get the required information promptly for problem solving and decision making. It is also essential to reduce the vertical level of the company because in a vertical level company structure communication between the upper and lower layers of management must be transmitted through many layers, resulting in redundancy and communication delays.

According to the framework developed by Duque and Cadavid (2007) for Lean Manufacturing implementation is presented in Figure 1.

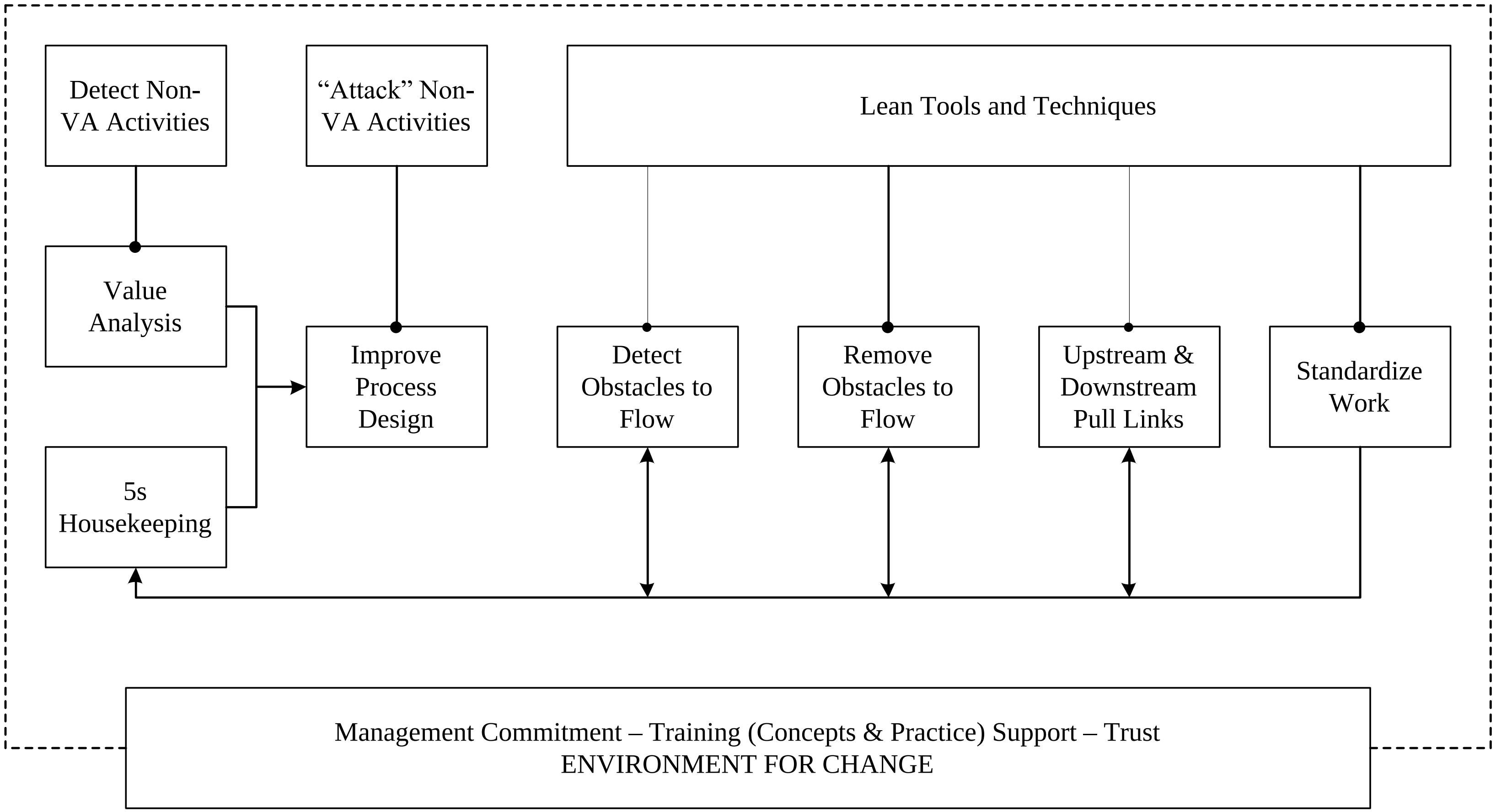

Figure 1: Framework for lean manufacturing implementation (Duque and Cadavid,2007)

2.5.5 Measuring Progress

It is necessary to progress and to assess the effectiveness and the different changes, tools and techniques that are implemented. For each of the improvement dimensions defined above, several indicators and metrics can show the progress. Summarizing Duque and Cadavid (2007), indictors for lean implementation measurement are presented in Table 1

Table 1: Indicators for lean implementation measurement

Improved Dimensions	**Metrics and Indicators**
Elimination of waste	Work in process (WIP): Value of WIP in the line Setup time: Time spent in setups/total productive time(percentage) Machine downtime: Hours-machine lost due to malfunction/Total machine hours Transportation: Number of cycles transported and distance Space Utilization: How much area does the line need, including its WIP and tools
Continuous improvement	Number of suggestions per employee per year. Percentage of suggestions that get implemented. Scrap: % of the products that needs to be scrapped. Rework: % of the units that needs to be sent to rework.
Continuous flow and pull driven systems	Lot sizes: Average lot size for each product. Order flow time: Time an order takes for processing on the shop floor. Order lead time: Average time from the placement of an order (by a customer) to its delivery. Pulling Processes: Percentage of the line processes that pull their inputs from their predecessors. Pull Value: % of the total annual value or throughput of the system that is scheduled through pull mechanisms.

Improved Dimensions	Metrics and Indicators
Multifunctional teams	Autonomous control: % of quality inspection carried out by the team. Work team Task Content: % of the tasks required to make the product performed by the team. Cross training: Average over team members of Number of skills a team member possesses/Number of skills needed in a team. Number of employees capable of assignment rotation.
Information systems	Frequency with which information is given to employees. Percentage of procedures that is documented in the company. Frequency with which the line or cell progress boards are updated.

Vieazindiene and Ciarniene (2013) presented a model for successful lean implementation as show in Figure 2.

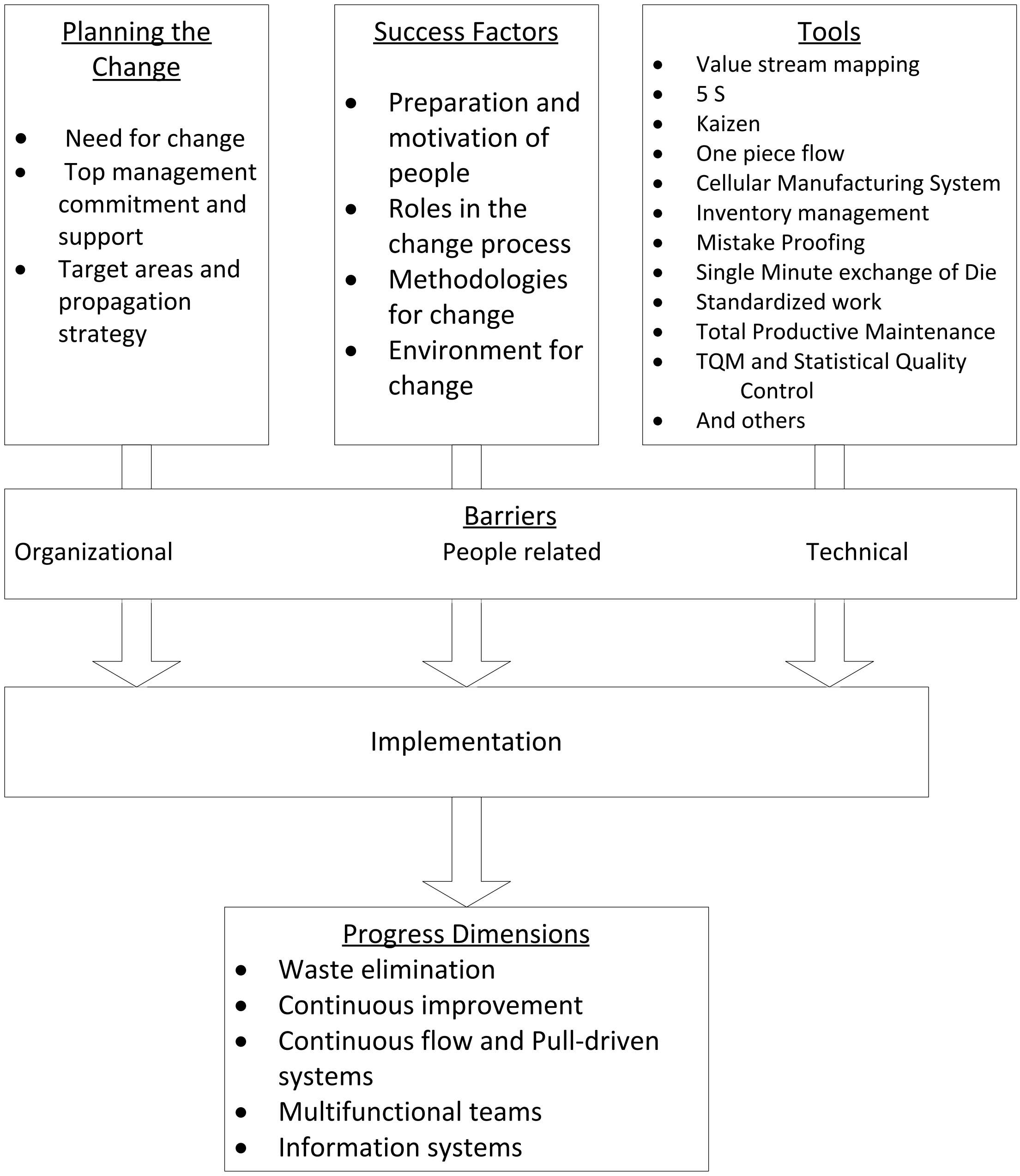

Figure 2: The model for successful lean implementation (Vieazindiene and Ciarniene, 2013)

2.6 Lean Construction

Lean manufacturing is a multi-dimensional management practice. In recent years implementation of lean philosophy in various industries has become increasingly popular and the manufacturing industry has made significant progress in increasing productivity and product quality. Improvements in manufacturing processes include reducing the amount of human effort, space in inventory required in the factory and increasing the quality and variants of products and the flexibility of manufacturing operations. If manufacturing can make such massive improvements in quality and productivity, why not construction?.

Lean manufacturing was a major influence on lean construction. Although the term "lean construction" was adopted nearly 20 years ago and it is still irritating to gain the momentum that lean manufacturing has gained in the manufacturing industry.

When comparing construction with manufacturing the construction process is similar to the factory manufacturing process, but it is different in the physical features of the end product. Also, construction is site position manufacturing as opposed to fix position manufacturing, and construction is one kind of production. So due to the success of lean principles in the manufacturing industry and potential of construction projects for optimizing productivity, applying lean production principles in the construction process seem to be effective.

As defined by the Lean Construction Institute, lean construction is "the application of lean thinking to the design and construction process creating improved project delivery to meet client needs and improved efficiency for the constructor".

The research done on Generic Implementation of Lean Concepts in simulation model by Farrar, Rizk and Mao (2004), presented a systemic approach to the application of lean production theory in computer simulation models. Further it gives the development of a special purpose computer simulation model which can be used in road construction surface work operations consisting of sub grade operations, aggregate operations, and asphalt operations. The research approach is very important in the construction industry because it helps users to apply lean principles to simulation models and bring them closer to applying these principles in actual construction projects.

2.7 Lean Application to Quarry Process

The operations of quarry sites are similar to factory production since they contain sequential production processes, tasks and activities to produce the output product. A quarry contains a set of overall main processes. These main processes are the same at all quarries even though the machines used for the sub processes depend on the availability and production capacity needed at the specific site.

A quarry site normally has different configurations and the whole process is based on the raw material that is created. The main processes that are considered in this work are those activities that are performed in sequence and/or parallel in time so that they can be synchronized and optimized with each other. These activities are loading, transporting, unloading and feeding to the crusher. In these operations at the quarry site there can be waste resulting from overproduction, waiting, processing, inventory/buffer, and unnecessary movements. This wastes can make an impact on the productivity of the quarry process. Hence it is important to assess the wastes taking place in quarry operations in order to get the real effect of the production process. Therefore by applying lean principles to quarry operations at a quarry site it is possible to identify potential improvement of productivity by eliminating waste in production process.

From lean concepts, the above mentioned activities in the quarry production process can be classified as value adding activities and non- value adding activities. Value adding activities are those that contribute value to the final product, and non-value adding activities are those that takes time, resources, or space but do not add value, (Koskela, 1992). According to lean principles, if non value adding activities can be reduced or eliminated, waste in the production process also can be reduced or eliminated.

Accordingly, the activities of quarry operations such as loading, unloading, and crusher plant operations can be classified as value adding activities, because they are essential steps in converting materials into final product. It is assumed that the crusher plant is located away from the quarry site. Therefore, transportation is also defined as a value-adding activity. Truck preparation and truck position are defined as non-value adding activities, because they do not add value to final production and could potentially be reduced or eliminated.

The research done on quarry site using Value Stream Mapping (VSM) technique obtained from time studies reveals that a major potential improvement was found in the area of transport, buffer/inventory handling as well as in the customer delivery/loading activity. Assessing the identified wastes resulting from over production, waiting, processing and inventory/buffer and unnecessary movements such as stop and go in the case studies, show potential for improvements and further optimization utilizing production control techniques,(Rylander and Axelsson, 2013).

2.8 Summary

This chapter presented the history and development of the lean principles and the importance of implementing lean manufacturing processes. In addition it described the general principles of lean manufacturing and how to plan the transformation process including lean tools, techniques and progress measuring dimensions. Further, it describes the application of lean principles in the construction industry and finally, lean application in quarry industry and the recommendations of the previous researchers were discussed in depth in this chapter.

CHAPTER 3

3.0 Research Methodology

3.1 General

This chapter focuses on the methodology used for this research. It starts with an introduction to quarry operation, crusher operation and cellular manufacturing. Then it deals with the framework of the research and describes the method of data collection, data processing and analysis of data. Finally it gives a summary of the section.

3.2 Quarry Operation

A quarry operation covers six main processes: Site establishment, Exploitation, Processing, Distribution, Maintenance and Reclamation, (Fu, 2013). Among these activities, the main process in quarry operation are exploitation, processing and distribution. Maintenance is done mainly to keep these processes under efficient operation over time. Site establishment is preparation of the site and the reclamation is done to reinstate the area in a proper way when it has been fully utilized. The steps of exploitation and processing include the initial phases of stone handling such as blasting/digging and transporting material to crushers. Normally blasting cannot be done in parallel with the other activities because of safety risks and therefore this activity can be excluded from the study since it cannot be synchronized in real-time.

The main processes considered within this work are those that are performed in sequence and/or in parallel time so that they can be synchronized and optimized with each other. Those processes are loading, transporting, unloading to the crusher and crusher operation. As in previous studies, potential improvements in loading, transporting and unloading processes are identified. The improved loading, transporting and unloading processes optimize the raw material supply to the crusher. With the optimized material supply, the crushing process was studied to identify the lean wastes in the two different crushing circuits.

3.3 Crusher Operation

3.3.1 Crushing Theory

The purpose of crushing is to prepare the aggregates for further processing. The crushing circuit is designed to produce a certain amount of a certain type of material to achieve the required production capacity. Crushing is linked with the relationship between the amounts of energy put into a rock or particle of a known size and the reduced particle size after the crushing process has taken place. The amount of energy required to do this work is referred to as the 'Crushing Work Index', which is a measure of the resistance of a material to crushing (or grinding). It is a measurement of how hard the rock is. The energy required for crushing depends on the hardness of the rock (Work Index), feed size and desired product size. The term "Specific Energy Input" refers to the amount of energy required to treat a certain tonnage of rock to crush from a feed size to the required product size.

3.3.2 Crushing Equipment

3.3.2.1 General Classification

The design requirements of size reduction machines mostly depend on changes in particle size. In virtually all machines, the breakage force is applied either by compression or impact. The products in each case are generally similar and the difference between machines is associated mainly with the mechanical aspects of applying force to the various sizes of particles. When the particle is large, the energy required to fracture each particle is high, even though the energy per unit mass is low. As the particle size decreases, the energy per unit mass rises more rapidly. Consequently, crushers have to be massive and structurally strong.

3.3.2.2 Jaw Crusher

Jaw crushers cause fracture by compression and this is the most practical method of applying a fracture force to very large particles. This, in turn, means that the machine must be constructed in such a way that the openings impose limitations on the feed and product size, so that capacity becomes dependent on the size of the discharge opening and the machine speed. The jaw crusher consists of two plates; set at an acute angle to each other, with one jaw pivoted called the swing jaw, so that it swings relative to the fixed jaw. Material fed into the jaw is alternatively nipped and released to fall further into the crushing chamber. A cross section of a jaw crusher is shown in Figure 3. Generally jaw crushers are used as primary crushers, which crush the bigger feed size into intermediate sizes.

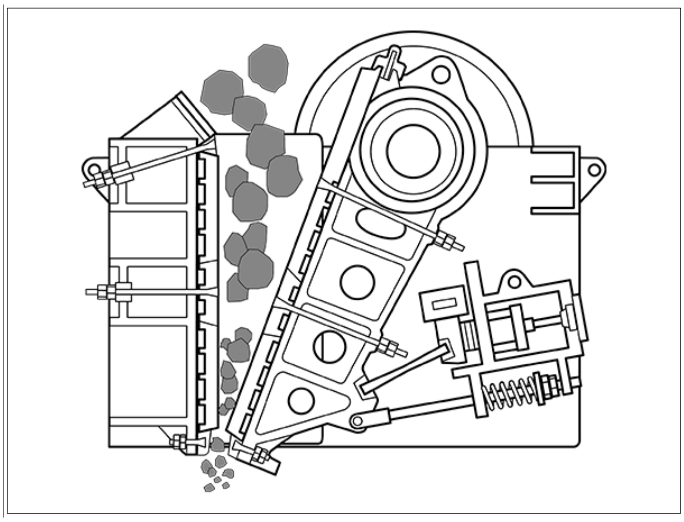

Figure 3 : Cross Section of a Jaw Crusher

3.3.2.3 Cone Crusher

A cone crusher crushes materials by the working surface between the movable cone (mantle) and fixed cone (bowl liner). It is more advanced and efficient than a jaw crusher. Figure 4 below shows the cross section of a cone crusher. It breaks rock by squeezing the rock between an eccentrically gyrating spindle, which is covered by a wear resistant mantle, and the enclosing concave hopper, covered by a manganese concave or a bowl liner. As the rock enters the top of the cone crusher, it becomes wedged and squeezed between the mantle and the bowl liner or concave. Large pieces of ore are broken once, and then fall to a lower position where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher.

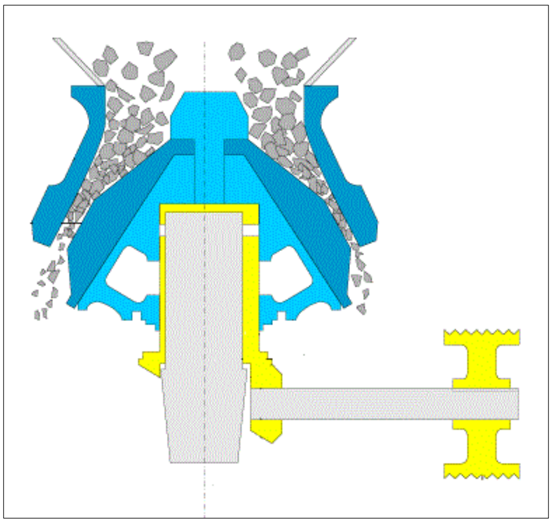

Figure 4: Cross Section of a Cone Crusher

A cone crusher is suitable for crushing a variety of mid-hard and above mid-hard rocks. It has the advantage of reliable construction, high productivity, easy adjustment and lower operational costs. The spring release system of a cone crusher acts as an overload protection that allows tramp to pass through the crushing chamber without damage to the crusher. Generally cone crushers are used as secondary and tertiary crushers that produce the required product sizes.

3.3.2.4 Impact crusher

Impact crushers consist of a high speed rotating impeller or hammer, which accelerates the incoming new feed to a high speed, to impact against a liner to cause rock breakage. Generally they are used on medium to soft ore types, with relatively low abrasion characteristics and low impact resistance. The products of these crushers are generally quite fine due to the large amount of power exerted on each particle as it passes through, causing shatter type fracturing. Thus impact crushers are capable of very high reduction ratios. Their capacities are quite high for the relatively compact size and low complexity of the crusher.

The two general types of impact crushers are Vertical Shaft Impactors and Horizontal Shaft Impactors. Generally, an impact crusher is used as a secondary and tertiary crusher to produce the required product sizes.

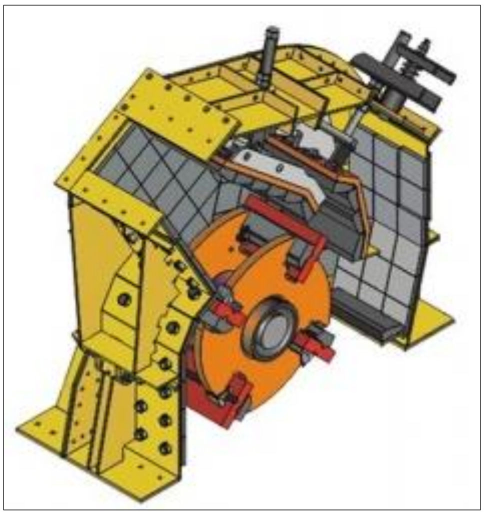

Figure 5: Impact Crusher

3.3.2.5 Bin and Feeders

Bins are used for surge capacity and can vary in size. Typically bins are located before the crushing equipment. Feeders are used to deliver rock in a controlled manner to screening and crushing equipment, and therefore their speed can usually be controlled. A typical crushing circuit will have a combination of apron feeders, vibrating feeders or reciprocating plate feeders. Vibrating feeders can have a grizzly incorporated into them.

Figure 6: Feeder

3.3.2.6 Vibratory Screens

In crushing plants screens are used for size separation of the ore being crushed. Generally aggregate that is undersized is sent onto the next stage of crushing and oversize ore is often returned to the circuit for further crushing. Screens can be designed in a single deck, double deck, or triple deck configuration, depending on the application required. The shape of the screen can be either conventional inclined, or “banana” shaped, which is steep at the feed end, with the angle decreasing towards the discharge end.

Figure 7: Vibratory Screen

3.3.2.7 Conveyors

Conveyors act as a means of moving material within crushing plants. They are preferred and common because they provide an even and continuous flow. Their mechanical efficiency is high as relatively little dead weight has to be moved with the load. Further, frictional resistance is low and power consuming starts and stops are relatively rare. Basically, a conveyor is an endless moving flat belt for transporting dry materials. The belt extends between a head pulley, and a tail or return pulley. It is supported by idler rollers, which are, in turn, supported by a frame. The drive pulley is often located at the head end or at an intermediate point along the return run. Tension in the belt is provided by either a "take up" or "gravity" pulley, located just behind the drive pulley, or an adjustable tail pulley.

Figure 8: Conveyor

3.3.3 Crushing Circuits and Stages

3.3.3.1 General Classification

It requires more energy to keep breaking rocks down to a smaller size. Crusher plants may use different strategies to achieve the crushing largely depending on the rock types. The most common strategy used, is multiple stage crushing to achieve higher capacity and product variety. In small production scales, single stage crushing is also applied. Circuit arrangement can be classified as open and closed. In an open circuit, crushed materials go to the final destination directly. In a closed circuit arrangement, crushed material is filtered by the screen, oversized material returning to the crusher and filtered material going to the destination.

3.3.3.2 Primary stage crushing

Primary stage crushing is employed to reduce the rock size 90mm – 200mm. Feeding rock size can be larger up to 1500mm. Primary stage crushing is arranged as an open circuit. There is no screening process and recirculating process. Crushed material goes to the final destination. Generally a jaw crusher is used for primary stage crushing. The product size is controlled by the discharge opening size. The crusher size is determined by the type and size of feeding rock.

3.3.3.3 Secondary stage crushing

Secondary stage crushing produces the required size of aggregates, generally 15 to 35 mm, using two types of crushers, typically a jaw and cone crusher. Other combinations of crushers may also be used, the jaw crusher as a primary and the impact crusher as a secondary crusher. Secondary stage crushing employs a combination of both open and closed circuit crushing. The primary jaw crusher is usually configured in an open circuit arrangement and the secondary cone crusher is normally configured in a closed circuit arrangement. In a closed circuit, the products from both crushers are screened, with the oversize from the screen being conveyed to the cone crusher again. The screen mesh size governs the size of the material leaving the circuit.

3.3.3.4 Tertiary Crushing

Tertiary stage crushing produces the aggregate size, generally 7 to 15 mm, using two or more types of crushers. If cone crushers are used for both secondary and tertiary purposes, it is common to install different head arrangements on each cone crusher. In this case, the standard head cone crusher becomes the secondary while the short head cone becomes the tertiary crusher. As with secondary stage crushing, tertiary crushing circuits employ a combination of both open and closed circuit crushing. The primary crusher is normally configured in an open circuit arrangement; while the secondary and tertiary crushers are commonly configured in closed circuit arrangement. In this closed circuit, the product from the crushers is screened using a double-deck screen with the top-deck oversize from the screen being returned to the secondary crusher and the intermediate size being delivered to the tertiary crushers. Again, the screen mesh size governs the size of the material leaving the circuit. The CSS on the secondary crusher can be set higher than in a secondary crushing circuit as this product will undergo further reduction in size through the tertiary crushers.

3.4 Cellular Manufacturing

3.4.1 Workcell

Cellular manufacturing is manufacturing done in a workcell. A workcell is a group of dissimilar operations formed to produce a product family. The basic building blocks of a workcell are workstations, workers, machines and means for holding and transferring items between workstations. The main benefits of cellular manufacturing are high quality and high efficiency. Cellular manufacturing greatly simplifies the production schedule and control, in cellular manufacturing tracking is divided into cells, not the whole production process at once.

3.4.2 Cellular Layout

Cellular layout is the arrangement of work stations or machines in the workcell. The cellular layout can be arranged in many shape and sizes. But the cellular layout should be arranged so as to eliminate wastes that can result from over transport, over motion, over process, over production, waiting in process and product defects. The sharing of machines and workers can be optimized by the cellular layout. For example, the motion of machinery and workers can be minimized by introducing a U shaped layout (Figure 09) rather than a straight layout (Figure 10). The each workcell can be linked with other workcells by mechanical feeders or conveyors.

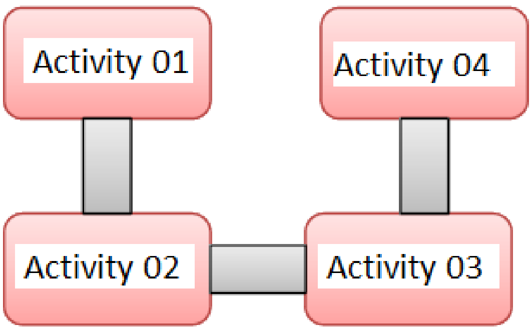

Figure 9: U Shape Layout

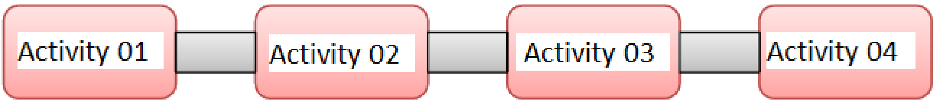

Figure 10: Straight Layout

3.4.3 Machining Workcell

In a machining workcel, all operations are done by machines; the machines are often automatic or semiautomatic. Single cycle machining means that the machining is done in a continuous flow and the machines are stopped after the machining operation is completed. In this process, machines are connected one to another by using a variety of devices. By introducing an intermediate buffer stock between the machines, the machines are allowed to operate somewhat independently. Then each machine acts as a sub cell having individual cycle times. The cycle time of the entire process depends on the sub cell having the longest cycle time. The independent operation of the machine is very useful when the process is with machines which need frequent maintenance.

3.5 Framework of the research

3.5.1 Research Approach

The research is based on a case study and is further extended to a time study and plant production data collected from observations and plant production records. The analysis is based on the data collected from two plants with different layouts, to find the lean wastes created as a result of the crusher circuit arrangements.

3.5.2 Selected plant complexes

3.5.2.1 Layouts of Plants

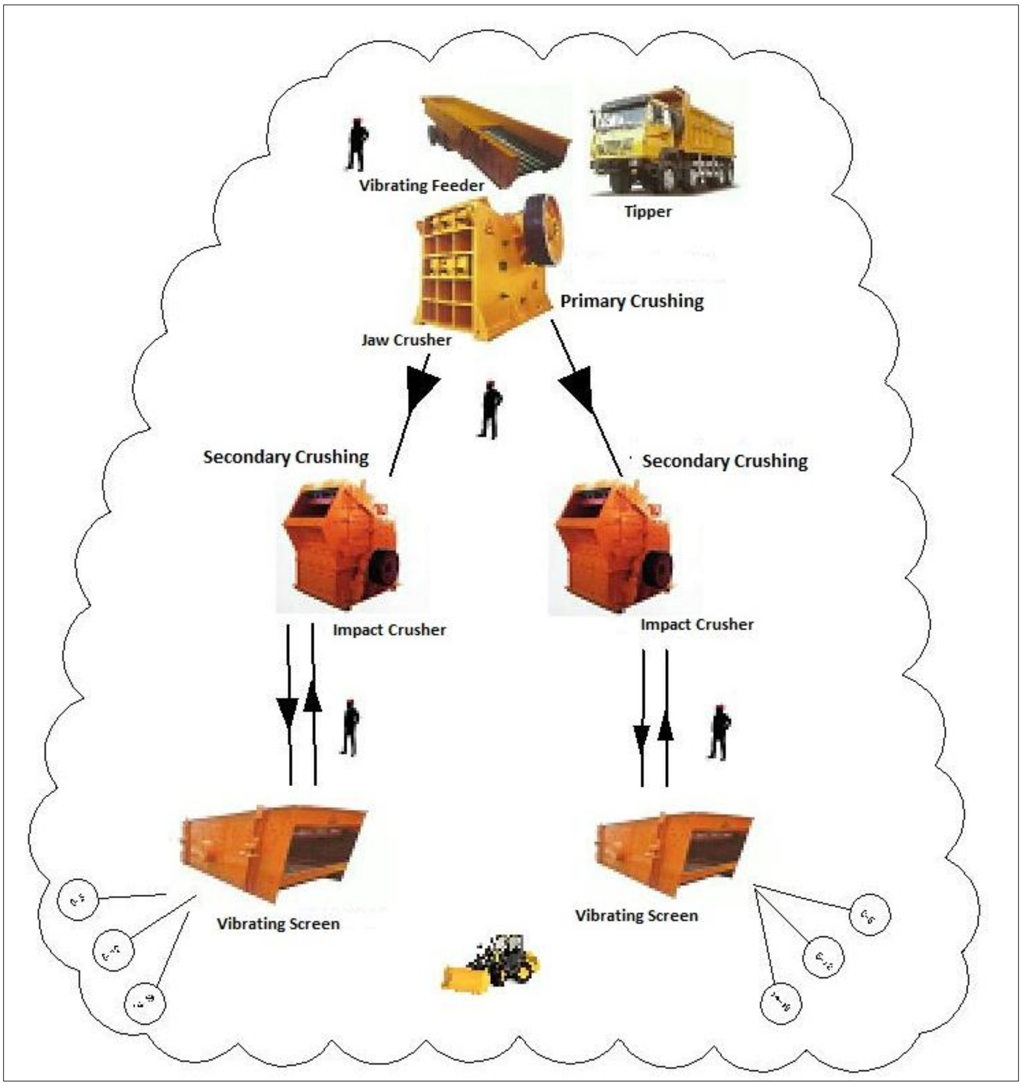

Figure 11: Layout of Plant No.01 (Two-stage in Single Cell)

Plant No.01, shown in Figure 11 is designed for two-stage of crushing. The 6”x9” size rubbles are fed in to the primary crusher through a feeder. Then the primary crushed materials (4”x6”) flow directly into two secondary crushers which are operated in parallel. The secondary crusher circuit is a closed circuit. The secondary crushed materials screened by vibrator screen and the required size materials are brought into the production belts. The oversized materials are returned to the crusher again. The primary and secondary crushing act is a continuous process in a single cell.

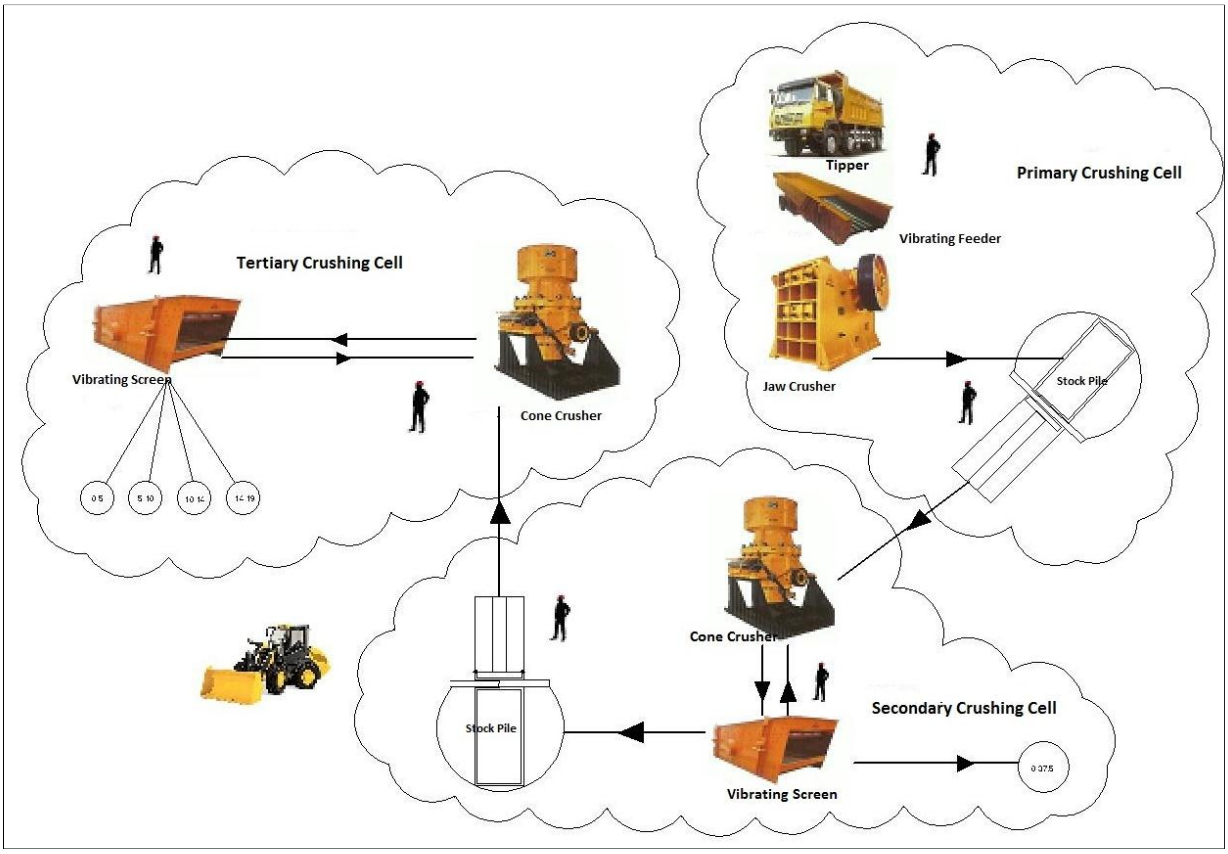

Figure 12: Layout of Plant No. 2 (Three-stage in Multi Cells)

Plant No.02, shown in Figure 12 has been designed for the three-stage of crushing which operate in three individual sub cells in a connected series. The process is divided into three sub cells by introducing two intermediate stockpiles. The vibrator feeder feeds 6” x 9” materials into primary crusher and crushed stones (4” x 5”) go to the intermediate stockpile No.01. The primary crusher acts as an open circuit in an individual cell. The secondary crusher is fed from stockpile No.1, and the secondary crushed materials are screened by a vibrator screen No.1. Then the smaller size materials are channeled to production belts according to sizes, and mid-size materials are channeled to the intermediate stockpile No.2. The oversized materials are returned to the secondary crusher again. The secondary crusher acts as a closed circuit in an individual cell. Finally the tertiary crusher is fed from stockpile No.2 and crushed materials are screened by vibrator screen No.2. Then smaller size material goes to the production belts according to sizes and oversized material goes to the returned channel of the tertiary crusher. The tertiary crusher also acts as a closed circuit in an individual cell. Therefore all primary, secondary and tertiary crushers act as individual cells in plant No.02.

3.5.2.2 Capacity of crusher plants

Plant No.1 consists of a jaw crusher for primary crushing and two impact crushers for secondary crushing. Plant No.2 consists of jaw crusher for primary crushing and two cone crusher for secondary crushing. Both plants have an overall crushing capacity of 150 tons/hour.

3.5.2.3 Product sizes of the plants

The two plants considered produce the same product sizes required in the construction industry. Both plants are fed with the same size rubble (6” x 9”). The feeding rock characteristics of hardness, toughness and abrasion are nearly equal and the quarries are situated in the same geographical area within a 6 km distance. The distance between quarry and plant is less than 500m and approximately equal for the both plants.

3.6 Method of Data collection

3.6.1 Initial preparation for data collection

Prior to starting the data collection for the analysis, a work study and time study were performed to identify synchronized processes of loading, transporting and unloading of raw material supplies. The above study was carried out by observation and data collection relating to each process, while the processes are executed in parallel. The processes that were studied were plotted on multiple activity charts to identify the lean wastes resulting from the processes. The mainly identified lean wastes of raw material supply is waiting at loading, for both plants. The waste during waiting at loading is eliminated by increasing the capacity of the loading excavator. The plant production data of the improved plant processes were taken for analyzing the crushing process. The multiple activity charts showing before improving and after improving of the both plants, are given in Appendix A.

3.6.2 The information system of the plant production

The information of the plant production system is divided into three categories.

1. Plant production and administration data
2. Stores transaction data
3. Plant / machinery repair and maintenance data

3.6.2.1 Plant production and administration data

The company has applied a rational system to capture more details of daily production information about the plants. The system has eleven forms to capture the data. Plants fill the forms daily, and proceed with that data to monthly production at end of each month. From the above system at the end of the month, company will be able to gather information like monthly production, material usage, machinery usage and manpower usage of each section. Other overhead information for the plant can be obtained from the organization's accounting system. The overhead will be distributed to the section of the plant proportionate to the production value.

The following documents have been identified as the information sources of the company:

1) Monthly Production Sheet (B01 as given in Appendix B)
2) Monthly Labour Involvement (B02 as given in Appendix B)
3) Monthly Machinery Involvement (B03 as given in Appendix B)

The above data is stored in a database system, and retrieved to calculate the production cost of each section. By this, the information can be produced with higher accuracy and in less time. The production cost of the crusher section is given by form No. B04 given in the Appendix B.

3.6.2.2 Stores transaction data

The aim of the stores management system is to minimize the cost of holding the stocks while ensuring that there are enough materials for production to continue and meet customer demand. The existing stores management system of the plant complex follows an ordinary stock management system, beginning with the material requisition form. The flow chart C01 given in Appendix C shows the stores management system of the organization. There are five documents involved in the stores procedure. The Form C02 is used for material requests, and proceed to Form C03 Purchase Order after approved of quotation. Form C04 Good Received Note is issued, when the materials received at the stores. When issuing material, Form C05 Advice of Dispatch note is used in the system. Finally, all receiving and issuing proceed to Form C06 stock book of the system.

The inventory level of these items is decided by the plant manager and stores manager based on their experience and future demand. The existing stores management system is based on the ordinary book keeping method. Therefore, retrieval of information supplier wise, customer wise, material wise, and time period wise is very intricate. The effectiveness of management decisions has an impact due to the low accuracy of data and increased time consumption in retrieval. But a database system provides a platform to organize, store and retrieve the planned and actual performance data with high accuracy and in less time. Therefore a new computerized inventory database system for stores management was introduced by the company. The inventory database system enhanced the information needed for the production costing and material reconciliation process. For example, raw materials supplied for plant production are taken from the inventory database for costing; the report format is given by Annex C07 in Appendix C.

3.6.2.3 Plant / machinery repair and maintenance data

In a company, repair and maintenance means maintaining and improving the quality of the elements involved in a production process. The process consists of scheduling jobs, assigning personnel, reserving materials, recording cost, and tracking relevant information such as the cause of the problem and recommendations for future action. Therefore the plant, machinery repair and maintenance system is responsible for assuring optimum use by the company.

The existing system uses three forms starting with Form D1 (given in Appendix D). It is used for requests to initiate maintenance and repair of vehicle, plant and machinery. Form D1 proceeds to Form D2 with the beginning of the job. After completing the job, Form D3 is used in the system. The form D3 includes total labour cost, material cost, and spare part cost of the job.

Retrieving or extracting the necessity data based on plant, vehicle or machinery, time period, and spare parts from the current record keeping system is very intricate procedure. Therefore the existing system is incapable of filtering the required information and the time it takes to access data is unlimited. It can take minutes, if not hours, to locate a few files in a large paper filing system. When looking something up requires a search through the system starting from the first entry until it is found.

By using database system instead of the existing system the company can overcame the above mentioned problems. Therefore, a database system was introduced to store and manipulate data about repair and maintenance of plant and machinery. The repair and maintenance information extracted from the above system improved the plant maintenance and production costing processes. For example, the monthly maintenance and repair cost of a plant extracted from the system is given in Annexe D04 in Appendix D.

3.7 Processing of Data

3.7.1 Plant production data

The improvements and methods mentioned under the Clause 3.6 were applied to the existing plant production system and plant production volume, raw material used, labour/machinery involved and non-production time were recorded on a daily basis and fed into the database. At end of the month, the above data was summarized process wise and used to calculate the production cost of each process. The cost of each process is given for plant, machinery labour and material used with the overhead cost. The above process was conducted for several months for the two plant systems in order to identify the lean wastes arising due to the plant layout.

The monthly plant production details of the Plant No.01 and Plant No. 02 are given by the Table 2 and Table 3 respectively, for the study period of plant process. The tables show the production volume for each month given by weighbridge measurements. The plant production hours were calculated by the hour meter of plant generators. Sundays are allocated for the scheduled plant maintenance. Scheduled and nonscheduled maintenance and repair hours were extracted from the maintenance records. The other factors affecting to the plant production quarry blasting, weigh bridge repairs, breakdown of excavator, dump trucks and water bowser and bad weather data are summarized and given in the Tables.

Table 2: Plant No.01 (Two-stage in Single Cell)

Month 2014	Crushed Boulders Qty	Working days per Month	Working Hours	Sunday Work	Production Loss Hours									Total
					Crusher plant		Generator		Other					
					Maint.	Brake down	GN 09	GN 14	Quarry Blasting	Weigh bridge	Lorry , Excavator Brake Down	Water Bowser Brake Down	rain	
March	26,046	24.00	216.00	5.00	4.00	17.00	5.40	7.00	0.35	1.45	1.45	0.30	3.50	**40.45**
April	14,741	15.00	115.00	2.00	2.50	21.00	1.30	0.00	0.50	0.00	1.10	0.00	5.45	**31.85**
May	28,978	22.00	206.00	4.00	5.50	28.00	4.00	7.00	4.00	0.00	2.00	0.25	10.40	**61.15**
June	24,442	23.00	204.00	5.00	5.00	15.00	3.00	3.00	0.20	0.00	0.75	0.00	8.00	**34.95**
July	33,787	25.00	229.00	4.00	6.00	14.10	1.45	1.10	0.45	0.45	0.00	0.45	1.00	**25.00**
August	31,115	25.00	223.50	5.00	5.50	15.30	1.80	2.00	1.10	0.00	0.00	0.00	16.30	**42.00**
Total	**159,109**	**134.00**	**1,193.50**	**25.00**	**28.50**	**110.40**	**16.95**	**20.10**	**6.60**	**1.90**	**5.30**	**1.00**	**44.65**	**235.40**
					175.95				**59.45**					

Table 3: Plant No 02 (Three-stage in Three Cells)

Month 2014	Crushed Boulders Qty	Working days per Month	Working Hours	Sunday Work	Production Loss Hours									Total
					Crusher plant		Generator		Other					
					Maint.	Brake down	GN 365	GN 500	Quarry Blasting	Weigh bridge	Lorry , Excavator Brake Down	Water BowserBrake Down	rain	
March	31,437	24.00	203.70	5.00	6.00	11.00	2.00	1.00	0.25	0.00	1.25	0.30	3.60	**25.40**
April	23,317	15.00	139.50	2.00	3.00	4.00	0.00	3.00	0.50	0.00	0.50	0.00	5.25	**16.25**
May	35,512	22.00	242.10	4.00	5.00	14.00	5.00	2.50	3.00	0.50	2.50	0.00	11.20	**43.70**
June	36,297	23.00	229.90	5.00	4.50	9.00	4.00	3.50	1.00	0.00	1.00	0.25	7.80	**31.05**
July	45,114	25.00	261.60	4.00	2.50	12.00	3.00	1.00	0.50	0.00	3.00	0.00	2.00	**24.00**
August	40,756	25.00	231.60	5.00	5.00	14.00	5.00	3.00	1.50	0.10	0.50	0.45	15.50	**45.05**
Total	**212,433**	**134.00**	**1,308.40**	**25.00**	**26.00**	**64.00**	**19.00**	**14.00**	**6.75**	**0.60**	**8.75**	**1.00**	**45.35**	**185.45**
					123.00				**62.45**					

Since Plant No.2 is in three sub cells, the sections of the plant are capable to run independently. Therefore for Plant No.2, the plant production hour losses were divided in to three categories. In first category 33% of the plant was stopped while 66% was running. In the second category, 66% of the plant was stopped while 33% was running. In the third category, 100% of the plant was stopped. The percentage of production hour loss with reference to plant production percentages is given in Table 4. The actual plant production hour loss in Table 4 calculated according to the equation below:-

$$\text{Actual Plant Production Loss} = \Sigma(\text{Production Loss Hr} \times \% \text{ of Plant Production} \times \% \text{ of Loss Hour})$$

Table 4: The Percentage of Production Hour Loss with Reference to Plant Production Percentage

Plant Production Loss Hours	Crusher plant		Generator		Other				
	Maint.	Brake down	GN 365	GN 500	Quarry Blasting	Weigh bridge	Lorry , Excavator Brake Down	Water Bowser Brake Down	rain
Production Loss Hours	26	64	19	14	6.75	0.6	8.75	1	45.35
	% of Hours								
33% Production Loss (1 cells not working)	60	72	0	70	0	100	78	0	0
66% Production Loss (2 cells not working)	18	12	75	0	0	0	8	0	0
100% Production Loss (3 cells not working)	12	16	25	30	100	0	4	100	100
Actual Plant Production Hour Loss	11.36	30.52	14.16	7.43	6.75	0.20	3.06	1.00	45.35
	63.46				56.36				

3.7.2 Plant Production Cost

The monthly plant production costs for the study period are given in Table 5 and Table 6 for the Plant No.01 and No.02 respectively. The production cost for each month has been broken down into five cost segments; manpower, machinery, fuel consumed, maintenance and the overhead. The production cost was calculated for crushing 1 ton of 6” x 9” rock into the required production sizes (0-30mm). Finally, the cost of 1 cube of 6” x 9” rock production was calculated taking the average bulk density of 6” x 9” as 4.56 ton / cube.

Table 5: Monthly Plant Production Cost of Plant No. 01

Month 2014	Manpower cost		Plant Diesel cost		Machinery Cost		Overhead		Repair & Maintenance Cost		Production Cost		Production (Ton)	Hauling Cost	
	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)		(Rs./Ton)	(Rs./Cube)
March	*14.36*	71.80	*67.25*	336.25	*36.53*	182.65	*52.63*	263.15	*48.25*	241.25	*219.02*	1,095.10	26,046.82	*73.56*	367.80
April	*12.44*	62.20	*60.23*	301.15	*38.16*	190.80	*63.38*	316.90	*46.23*	231.15	*220.44*	1,102.20	14,741.34	*71.45*	357.25
May	*15.76*	78.80	*61.52*	307.60	*40.98*	204.90	*59.23*	296.15	*45.69*	228.45	*223.18*	1,115.90	28,978.00	*69.68*	348.40
June	*11.37*	56.85	*58.31*	291.55	*41.13*	205.65	*54.26*	271.30	*47.56*	237.80	*212.63*	1,063.15	24,442.66	*70.23*	351.15
July	*16.67*	83.35	*56.51*	282.55	*34.14*	170.70	*55.65*	278.25	*49.63*	248.15	*212.60*	1,063.00	33,787.35	*72.56*	362.80
August	*14.78*	73.90	*65.46*	327.30	*38.89*	194.45	*43.47*	217.35	*47.36*	236.80	*209.96*	1,049.80	31,115.00	*78.27*	391.35

Table 6: Monthly Plant Production Cost of Plant No.02

Month 2014	Manpower cost		Plant Diesel cost		Machinery Cost		Overhead		Repair & Maintenance Cost		Production Cost		Production (Ton)	Hauling Cost	
	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)	(Rs./Ton)	(Rs./Cube)		(Rs./Ton)	(Rs./Cube)
March	*19.89*	99.45	*77.49*	387.45	*48.07*	240.35	*58.95*	294.75	*50.30*	251.50	*254.70*	1,273.50	31,436.59	*71.77*	358.85
April	*17.23*	86.15	*72.00*	360.00	*45.97*	229.85	*69.54*	347.70	*45.36*	226.80	*250.10*	1,250.50	23,317.01	*82.19*	410.95
May	*18.36*	91.80	*73.34*	366.70	*46.57*	232.85	*63.16*	315.80	*51.54*	257.70	*252.97*	1,264.85	35,511.52	*85.90*	429.50
June	*17.91*	89.55	*70.04*	350.20	*46.21*	231.05	*51.62*	258.10	*48.05*	240.25	*233.83*	1,169.15	36,297.19	*80.79*	403.95
July	*16.92*	84.60	*69.13*	345.65	*47.41*	237.05	*64.91*	324.55	*52.87*	264.35	*251.24*	1,256.20	45,114.45	*76.28*	381.40
August	*17.56*	87.80	*75.03*	375.15	*49.53*	247.65	*48.29*	241.45	*43.78*	218.90	*234.19*	1,170.95	40,755.87	*79.56*	397.80

3.7.3 Energy consumption

The raw materials for the two plants have the same characteristics. Therefore rock specific energy values of crushing should be nearly equal. But energy consumed by the crushers is different because of the two different crushing circuits. In Plant No.01 material was moved by three conveyors for completing the crushing process and it consumed total power of 550kw. In Plant No.02 material was moved by seven conveyors for completing the process and it consumed total power of 670kw. The power consumed by each plant for the study period is given in Table 7 and Table 8. The power consumed was converted to kwhr, assuming 1Ltr Diesel = 3.2 kwhr.

Table 7: Power Consumption of Plant No.01

Month	Production (Ton)	Diesel Consumption (Ltr/Ton)	Power Consumption (Kw/Ton)	Power Consumption (Kw/Cube)
Mar-2014	26,046.82	*0.554*	*1.774*	*8.871*
Apr-2014	14,741.34	*0.497*	*1.589*	*7.945*
May-2014	28,978.00	*0.507*	*1.623*	*8.115*
Jun-2014	24,442.66	*0.481*	*1.538*	*7.691*
Jul-2014	33,787.35	*0.466*	*1.491*	*7.454*
Aug-2014	31,115.00	*0.540*	*1.727*	*8.634*

Table 8: Power Consumption of Plant No.02

Month	Production (Ton)	Diesel Consumption (Ltr/Ton)	Power Consumption (Kw/Ton)	Power Consumption (Kw/Cube)
Mar-2014	31,436.59	*0.639*	*2.044*	*10.221*
Apr-2014	23,317.01	*0.594*	*1.899*	*9.497*
May-2014	35,511.52	*0.605*	*1.935*	*9.674*
Jun-2014	36,297.19	*0.577*	*1.848*	*9.239*
Jul-2014	45,114.45	*0.570*	*1.824*	*9.119*
Aug-2014	40,755.87	*0.619*	*1.979*	*9.897*

3.8 Method of Data analysis

Since the research study was based on crushing layouts, the data relevant to the crushing process was considered only for the analysis. The crushing production data was analyzed based on the cost segments, which are manpower, machinery and power usage for both plants. Manpower, machinery and diesel power costs were calculated for the production of 1 ton aggregates. The calculations of the labour and machinery rates were considered as same for the considered time period. Apart from that, plant productivity was obtained considering the plant production hours and considering non-production hours due to various reasons such as plant breakdown, machinery and generator breakdown, quarry blasting and bad weather. Then the considered parameters of productivity, usage of machinery and manpower and fuel consumption were tabulated to compare the plant layouts.

3.9 Summary

This chapter described the methodology employed to carry out the research. The framework of the research, methods of data collection and data processing were discussed. Two different crusher circuits, two-stage crushing in single cell and three-stage crushing in three cells were taken into consideration for the study. As discussed in the literature review, precautions were taken to eliminate the lean wastes that can take place supplying raw material for the plants. Then the data was collected from the observations and production reports of the plants. The collected data was processed based on the productivity, manpower and machinery usage, and power consumption. Finally this chapter discussed the method of data analysis to achieve the objective of the research.

CHAPTER 4

4.0 Analysis & Discussion

4.1 General

This chapter focuses on the quantitative research approaches selected and discussed in the previous chapter. It summarizes and discusses the data obtained from the two plants selected.

4.2 Availability of Crushing Circuits

Availability is the ratio of operation time which is planned, less down time, to planned operation time.

$$Availability = \frac{Actual\ operation\ time}{Planned\ operation\ time}$$

Availability of the crushing process in two crushing circuits is obtained from the ratio of total planned working hours less production lost hours due to plant breakdown, maintenance and other factors to planned operation time of the crusher.

4.2.1 Analysis of Availability for Two Crushing Circuits

For the selected study period, from March to August in 2014, data was obtained from the plant production records in the two plants selected - Plant No.01 and Plant No.02. A period of hundred and thirty four days was used to examine the operations of Plant No.01 and Plant No.02. This is considered as the study period for the research.

Plant No.01 was designed for two-stage crushing in a single cell, the total working hours were 1424.18 and the total production lost hours due to breakdown and maintenance were 175.95. It was the same as in Plant No.02 which does three-stage crushing in multi cells; it had 1428.22 total plant working hours and 63.46 production lost hours due to breakdown and maintenance. It was approximately 12.35% of total plant working hours in Plant No.01 and 4.44% in Plant No.02. There is difference between the production lost hours caused by breakdown and maintenance in Plant No.01 and Plant No.02. But the production lost hours caused by other factors such as blasting, weighbridge, and lorry or excavator breakdown are almost same in both Plant No.01 and Plant No.02. According to the data obtained from plant production records for the study period, production lost hours due to the other factors were 54.74 for Plant

No.01 and 56.36 for Plant No.02. The summary of the above plant production data collected from plant production records is given in Table 09 and Table 10 below.

Table 9: Availability of Plant No.01

Plant No.1 (2 Stage in Single cells)	Hours	%
Plant Working	1193.50	83.80
Production Loss (Breakdown & Main)	175.95	12.35
Production Loss (Other factors)	54.73	3.84
Total	1424.18	100.00

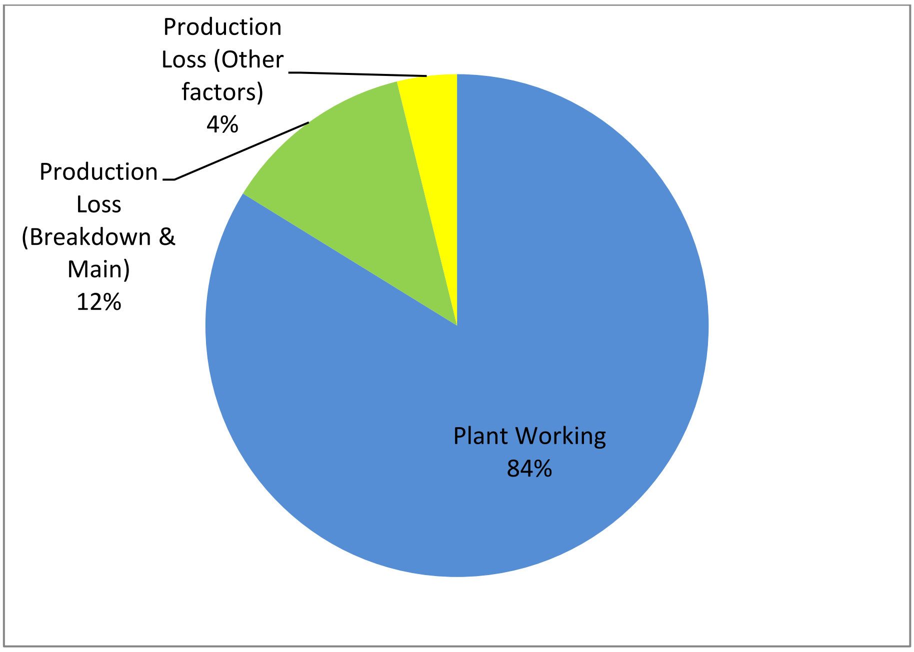

Figure 13: Availability of Plant No.01

Table 10: Availability of plant No.02

Plant No.2 (3 Stage in Three cells)	Hours	%
Plant Working	1308.40	91.61
Production Loss (Breakdown & Main)	63.46	4.44
Production Loss (Other factors)	56.36	3.95
Total	1428.22	100.00

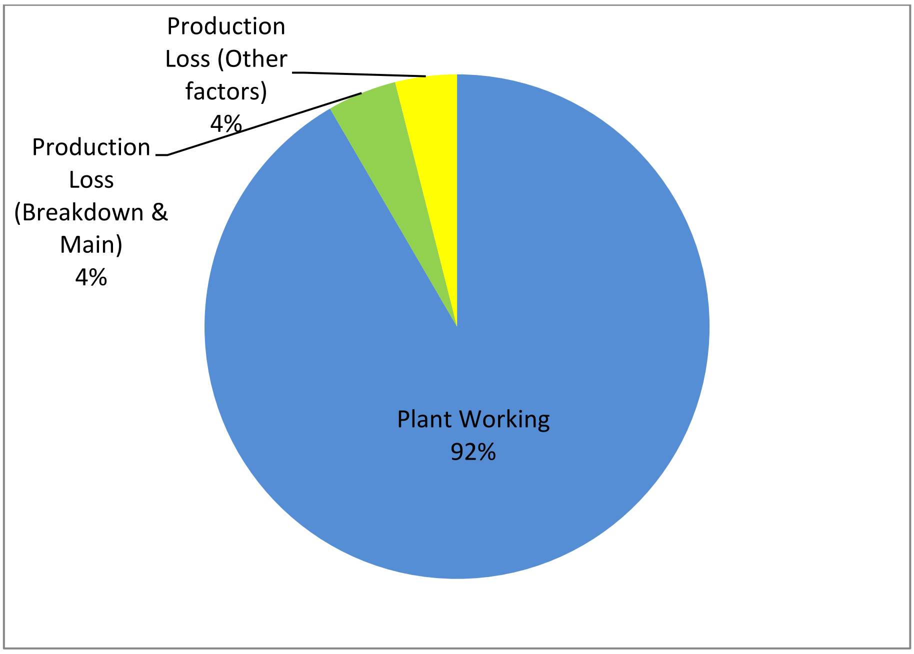

Figure 14: Availability of Plant No.02

In Plant No.01, primary crushing and secondary crushing with the total plant is done in one cell. The primary crusher capacity is divided into two at secondary crushing. Therefore Plant No.01 is more susceptible to failure .Minor faults can be dealt with by stopping the whole process. Because single section breakdown results in breakdown other two sections as well, leading to increased waiting time and reduced availability.

However in Plant No.02 crushing is done in three-stage and crushers are divided into three cells. Therefore crushers can be worked as individual sections. Thus the Plant No.02 circuit allows to run individual sections while other section is in repair. This decreases the Plant No.02 production lost hours due to breakdown and maintenance compared to Plant No.01. A reduction in the total breakdown and maintenance lost hours will reduce the total waiting time, leading in turn, to increased availability.

4.3 Discussion of Crushing Circuit Availability

Considering the availability of single cells and multi cells as illustrated in Figure 15, the multi cell crushing circuit was able to maintain production lost hours at 8%, while the single cell circuit was at a 16% higher value.

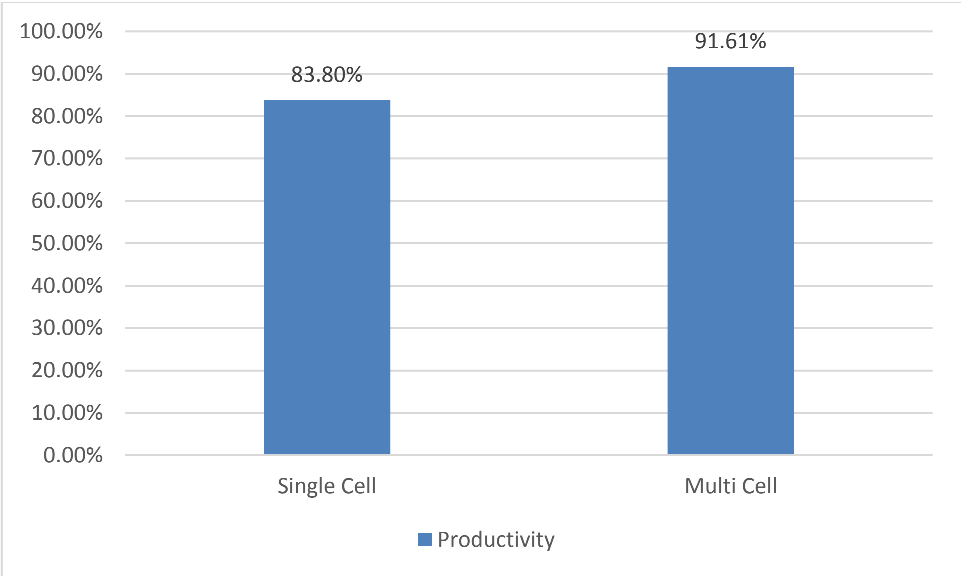

Figure 15: Availability of Single Cell & Multi Cell

As the availability analysis of the two crusher layouts shows, the multi cell process arrangement is able to minimize lean waste waiting in the process since the cellular crushing layout allows individual cells to operate independently while other cells are being repaired or are under maintenance.

4.4 Analysis of Machinery and Manpower Involvement

In Tables 11 and 12 show the machinery and manpower costs of Plant No.01 and Pant No.02 for each month in the selected study period. The average machinery and manpower costs for the selected time period are shown in Figure 16 and 17. For Plant No.01 the average machinery cost for production of one cube of aggregate is Rs196.06 while for Plant No.02 it is Rs241.90. Likewise average manpower costs for production of one cube of aggregate is Rs73.23 and Rs86.89 for the Plant No.01 and Plant No.02 respectively.

Table 11: Machinery Cost of Plant No.01 & Plant No.02 (Production Average 5000 Cube/Month)

Month	Plant No.01		Plant No.02	
	Machinery Cost (Rs./Ton)	Plant No.01 Crusher plant Machinery Cost (Rs./Cube)	Machinery Cost (Rs./Cube)	Plant No.02 Crusher plant Machinery Cost (Rs./Cube)
Mar-2014	39.59	**197.94**	54.23	**271.15**
Apr-2014	38.89	**194.46**	49.23	**246.15**
May-2014	36.53	**182.67**	48.07	**240.35**
Jun-2014	38.16	**190.78**	45.97	**229.85**
Jul-2014	40.98	**204.91**	46.57	**232.85**
Aug-2014	41.13	**205.63**	46.21	**231.05**
Average	39.21	**196.06**	48.38	**241.90**

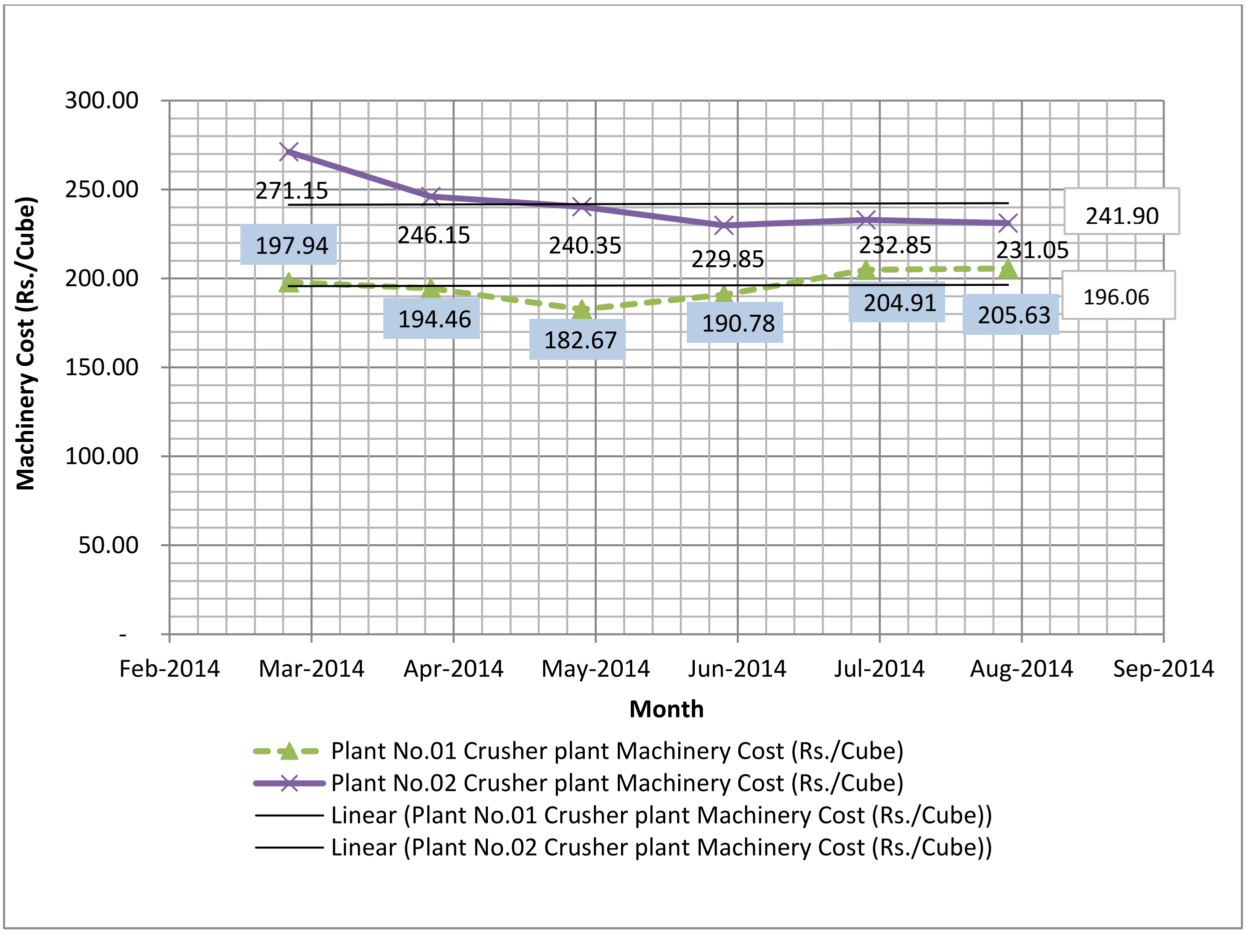

Figure 16: Machinery Cost of Plant No.01 & Plant No.02 (Production Average 5000 Cube/Month)

Table 12: Manpower Cost of Plant No.01 & Plant No.02 (Production Average 5000 Cube/Month)

Month	Plant No.01		Plant No.02	
	Manpower cost (Rs./Ton)	Plant No.01 Crusher plant Manpower cost (Rs./Cube)	Manpower cost (Rs./Ton)	Plant No.02 Crusher plant Manpower cost (Rs./Cube)
Mar-2014	15.23	**76.15**	18.35	**91.75**
Apr-2014	14.71	**73.56**	16.53	**82.65**
May-2014	14.36	**71.78**	18.89	**94.45**
Jun-2014	14.44	**72.22**	16.23	**81.15**
Jul-2014	14.76	**73.78**	17.36	**86.80**
Aug-2014	14.37	**71.87**	16.91	**84.55**
Average	**14.65**	**73.23**	**17.38**	**86.89**

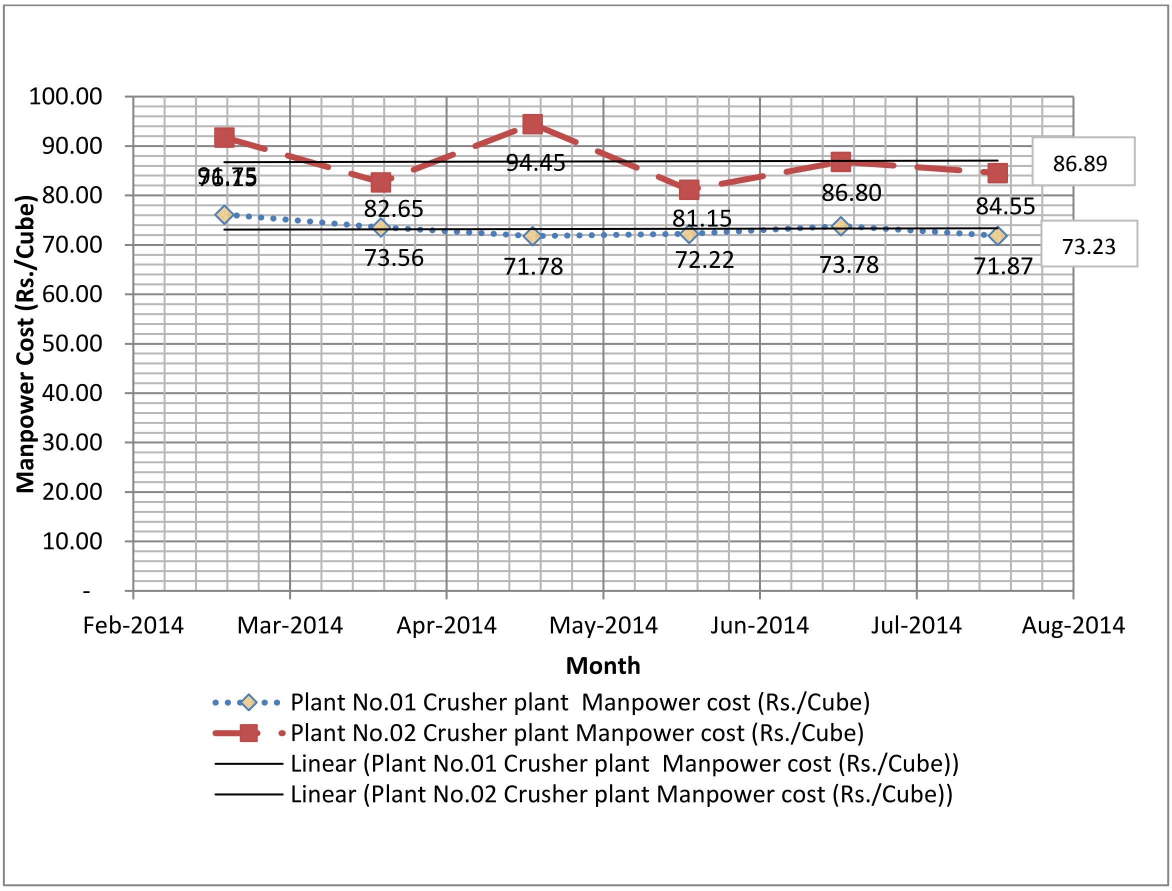

Figure 17: Manpower Cost of Plant No.01 & Plant No.02 (Production Average 5000 Cube/Month)

Based on the above analysis, machinery and manpower cost for Plant No. 02 is higher than Plant No.01 since the utilization of machinery and manpower is higher in Plant No.02 than in Plant No.01. Plant No.01 has two-stage crushing in single cell material moved by three conveyors while in Plant No.02 has three-stage multi cell, material moved by seven conveyors resulting in increased waste over conveyance in Plant No.02. Consequently the two different layouts of Plant No.01 and Plant No.02 service have to cover a large area in Plant No.02 in parallel with Plant No.01. Thus there is increased the waste over motion of machinery. And similarly, utilization of manpower is also high in Plant No.02, compared to Plant No.01.

4.5 Discussion of Machinery and Manpower Involvement

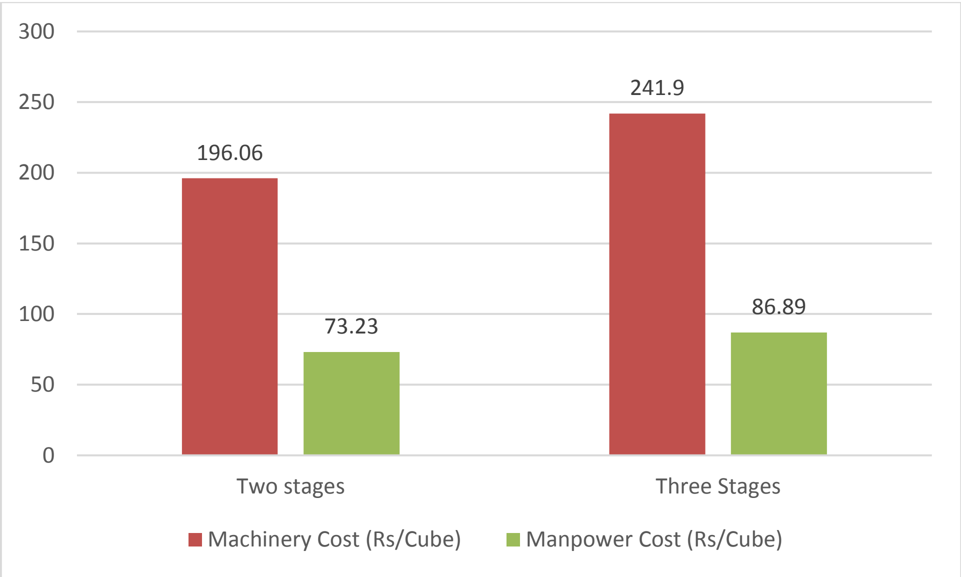

Figure 18: Machinery and Manpower Cost of Two-stage & Three-stage

Based on the analysis of the results, Figure 18 illustrates that the cost of machinery for production of 1 cube of aggregate in the two-stage crushing circuit is Rs 196.06 while in the three-stage crushing circuit it is Rs 241.90. Similarly manpower cost of production of 1 cube of aggregate in the two-stage crushing circuit is Rs 73.23, while three-stage crushing circuit is Rs 86.89. This indicates that both machinery and manpower costs are lower in the two-stage crushing circuit than in the three-stage crushing circuit. This analysis shows that machinery and manpower utilization in two-stage crushing circuit has eliminated the waste over conveyance, over motion and over utilization happening in the three-stage crushing circuit. The minimization of waste has led to a reduction in the utilization of manpower and machinery in the two-stage crushing circuit.

4.6 Analysis of Energy Consumption in Two Circuits

Total energy consumption in the study period in Plant No.01 and Plant No.02 for each month is given in Table 13. According to the data analysis data as shows in Figure 19 average power consumption in Plant No.02 is more than in Plant No.01. It is 8.12 kw/cube in Plant No.01 and 9.61 kw/cube in Plant No.02. This is because Plant No.01 only uses three conveyors for moving material in a single stage whereas in Plant No.02 uses seven conveyors for completing the same process. And also utilization of machinery is high in Plant No.02 resulting in increased energy consumption in Plant No.02.

Table 13: Power Consumption of Plant No.01 and Plant No.02 (Kw/Cube)

	March-14	April-14	May-14	June-14	July-14	August-14
Plant No.01	8.871	7.945	8.115	7.691	7.454	8.634
Plant No.02	10.221	9.497	9.674	9.239	9.119	9.897

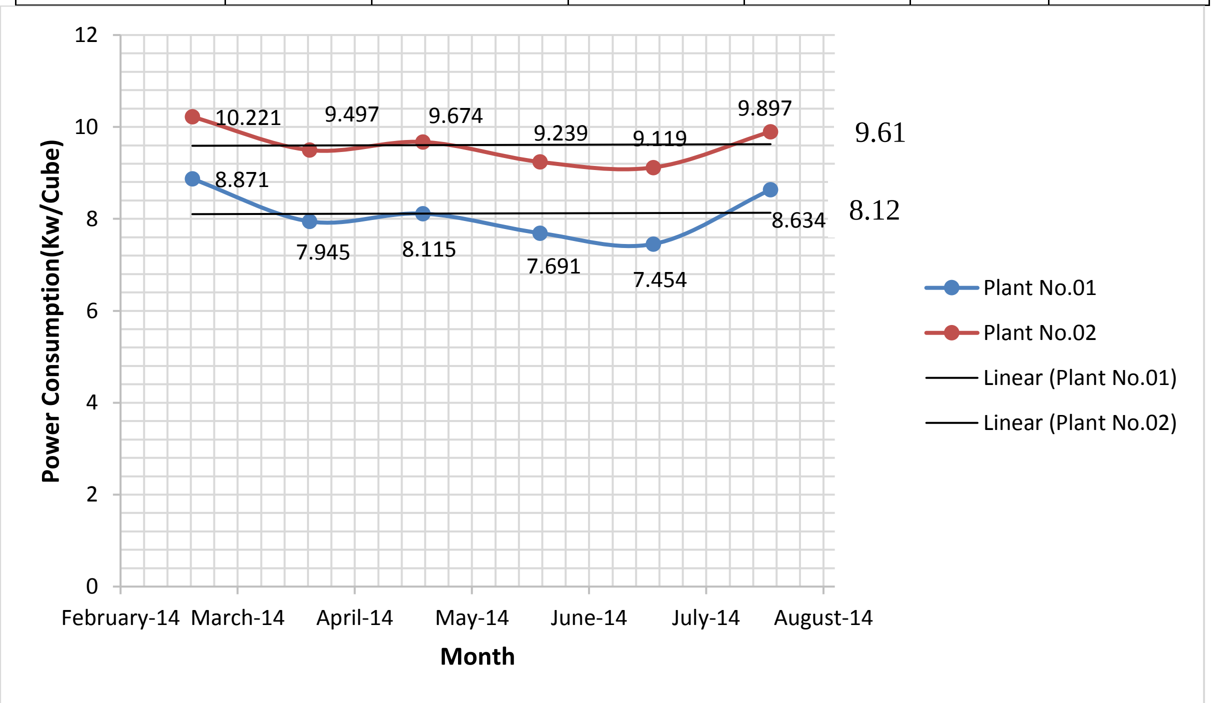

Figure 19 : Power Consumption of Plant No.01 and Plant No.02 (Kw/Cube)

4.7 Discussion of Energy Consumption in the Two Circuits

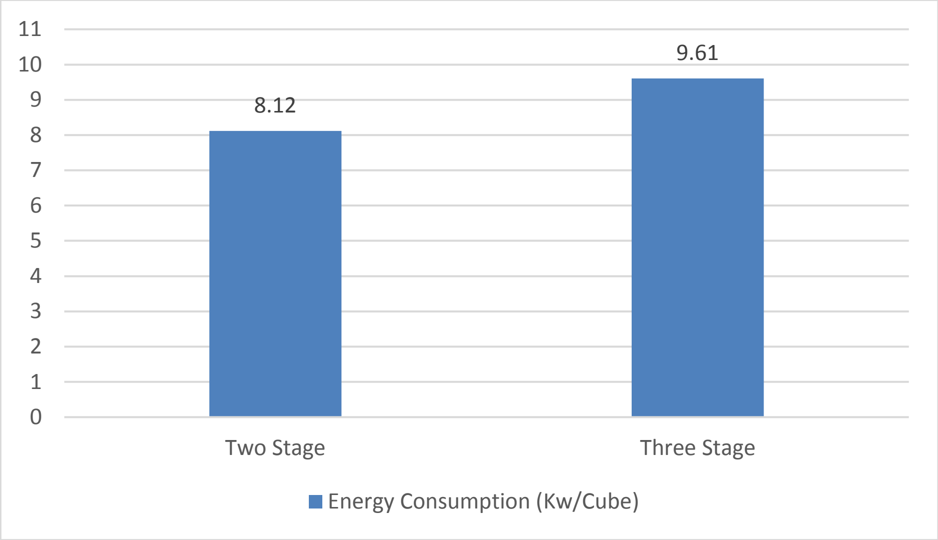

Figure 20: Energy Consumption of Two-stage and Three-stage

Based on the analysis, Figure 20 indicates that the energy consumption for the production of 1 cube aggregate in the two-stage crushing circuit is 8.12 Kw while in the three-stage crushing circuit it is 9.61 Kw. This indicates that energy consumption is lower in the two-stage crushing circuit than in the three-stage crushing circuit. The two-stage crushing circuit has eliminated the waste of over conveyance, over processing than in the three-stage crushing circuit. The above minimization of waste led to reduced energy consumption in the two-stage crushing circuit.

4.8 Summary

This chapter analyzed the processed data of the two crushing circuits. The analysis was based on the

- Availability of two crusher plants circuits
- Machinery, manpower and energy consumption of two crusher plants circuits

Finally, the different crusher plants circuit principle were discussed.

a. Multi cell vs. single cell
b. Two-stage vs. three-stage

The findings and conclusions are summarized in the next chapter

CHAPTER 5

5.0 Conclusions and Recommendations

5.1 Summary of Findings

The research findings relate to two different crusher circuit principles; cellular crushing and number of crushing stages.

1. Availability of crusher circuits
   I. Single cell crusher circuit – 84%
   II. Multi cell crusher circuit – 92%
2. Machinery cost of production of 1 cube of aggregate
   I. Two-stage crushing – Rs196.06
   II. Three-stage crushing – Rs241.90
3. Manpower cost of production of 1 cube of aggregate
   I. Two-stage crushing – Rs73.23
   II. Three-stage crushing – Rs86.89
4. Power consumption for production of 1 cube of aggregate
   I. Two-stage crushing – 8.12 Kw
   II. Three-stage crushing – 9.61 Kw

5.2 Conclusion

This thesis presents the lean waste happening in crushing operation in quarry process. The study is based on two different crushing circuits, both crushing circuits are horizontal flow. The first circuit is two-stage crushing in single cell and the second circuit is three-stage crushing in three cells.

The study emphasizes that the cellular crushing circuit reduces the down time of the system. This cellular arrangement allows for production in sections while allowing for maintenance in other sections of the system. Therefore the lean waste waiting in the process can be eliminated. The buffer stocks between cells are made more flexible by changing the production type based on customer demand.

A comparison of two-stage and three-stage crushing shows that the utilization of machinery, manpower and power is less in two-stage crushing. In three-stage crushing more wastes take place in the process of conveyance, motion of machinery and the use of manpower than in two-stage crushing. Therefore two-stage crushing is more cost effective than three-stage crushing considering lean wastes taking place in the process.

5.3 Recommendation

It is recommended that a two-stage crushing circuit with cellular manufacturing leads to more productivity by reducing wastes happening in inputs. The productivity improvement resulting from the proposed crushing circuit, will lead to reduced costs of aggregate production and help to maintain a competitive product price in the industry. The proposed two-stage crushing circuit is shown by Figure 21. The first stages are run in an individual cell with an intermediate buffer stockpile. Two secondary crushers running in parallel are fed from the buffer stockpile. The production materials are screened and channeled by vibrator screens for stockpiles according to the production sizes.

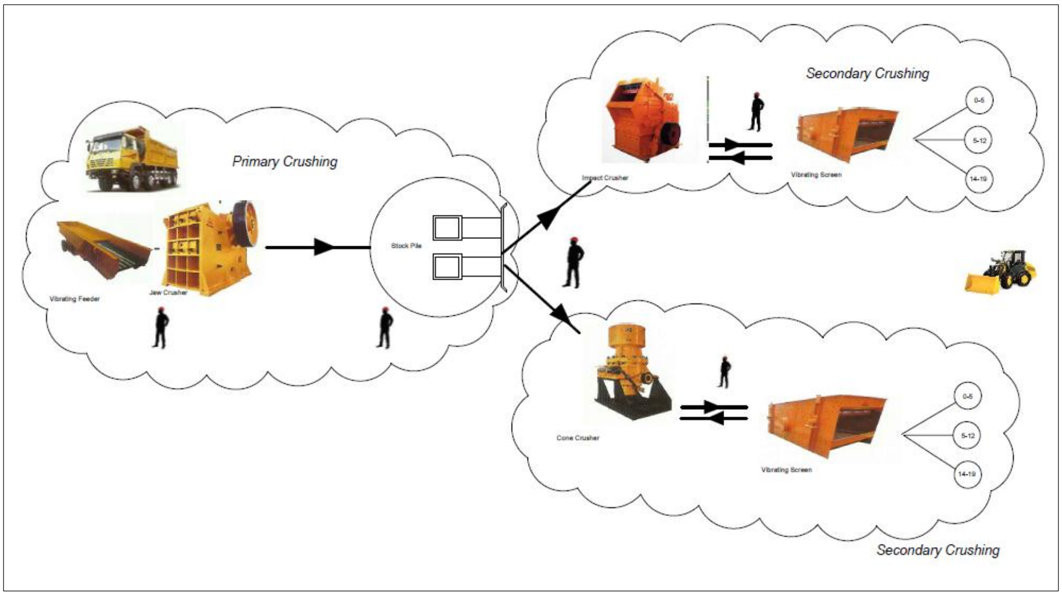

Figure 21: Proposed Plant Layout

5.4 Implementation

The crushing plant circuit recommended in this study was implemented by NEM Construction (Pvt) Ltd for their new plant at Beliatta in Southern Province. For the proposed crusher circuit, the plant vendor developed the plant design. The drawing developed by the vendor based on the proposed layout is given in Figure 22. The implementation was started in October 2014 and completed in December 2014.

This is the only plant in Sri Lanka with this specific layout. It is energy saving and therefore more productive. Photos of plant implementation stages are given by Figure 23 and 24. Figure 23 shows first stage of crushing and Figure 24 shows second stage.

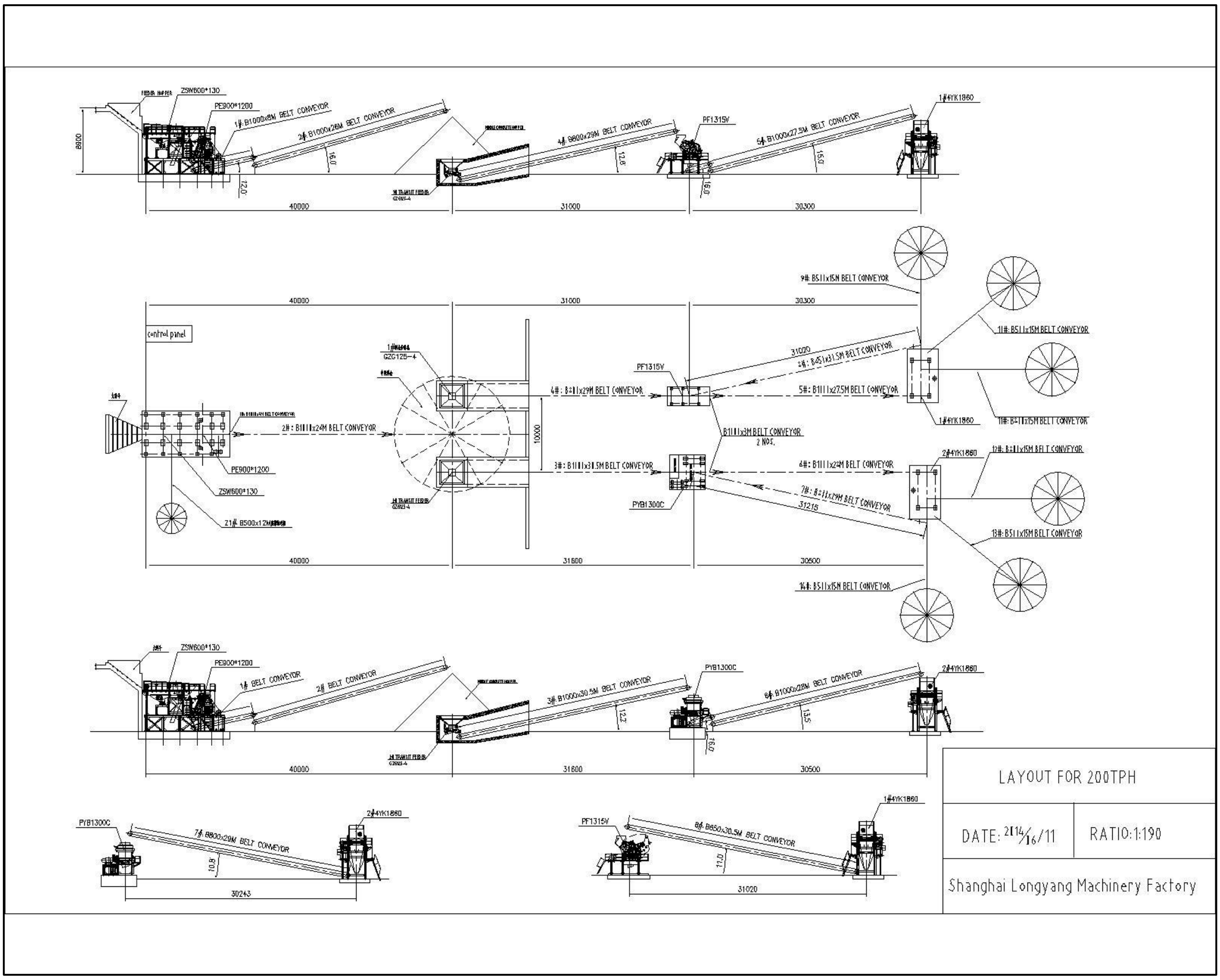

Figure 22: Drawing Developed by a Vendor Based on Proposed Layout

Figure 23: First Stage Crushing in Proposed Crusher Plant

Figure 24: Second Stage Crushing in Proposed Crusher Plant

5.5 Recommendations for Future Study

In this research, the selected crushing circuits were limited to horizontal flow circuits. In the Sri Lankan construction industry, vertical flow crushing circuits are not much practiced due to high structural costs at the initial stage. Future studies could be carried out to find out the cost effectiveness of vertical crushing circuits and horizontal crushing circuits. The study could cover the cost components, initial structural cost, utilization of manpower, machinery and electricity power and the availability of the system.

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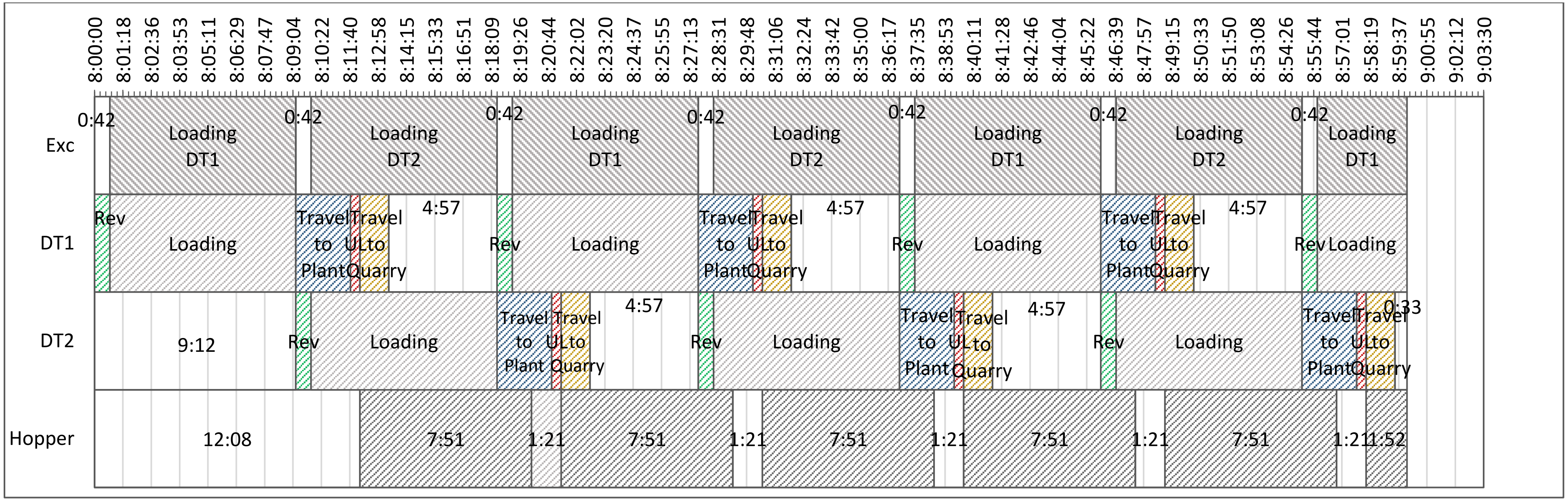
APPENDIX A

Reversing	0:42	min
Loading	8:30	min
Traveling	2:30	min
Unloading	0:26	min
Traveling back	1:19	min
Plant	130	ton/hr
DT	17	ton
Excavator	120	ton/hr
Hopper	40	ton

Cycle Time	13:27		
	Loading waiting	Unloading waiting	waiting at hopper
DT1	14:51	0:00	0:00
DT2	10:27	0:00	0:00
Excavator	0:00		

Plant Idling 6:46 min
Production 89.04 ton



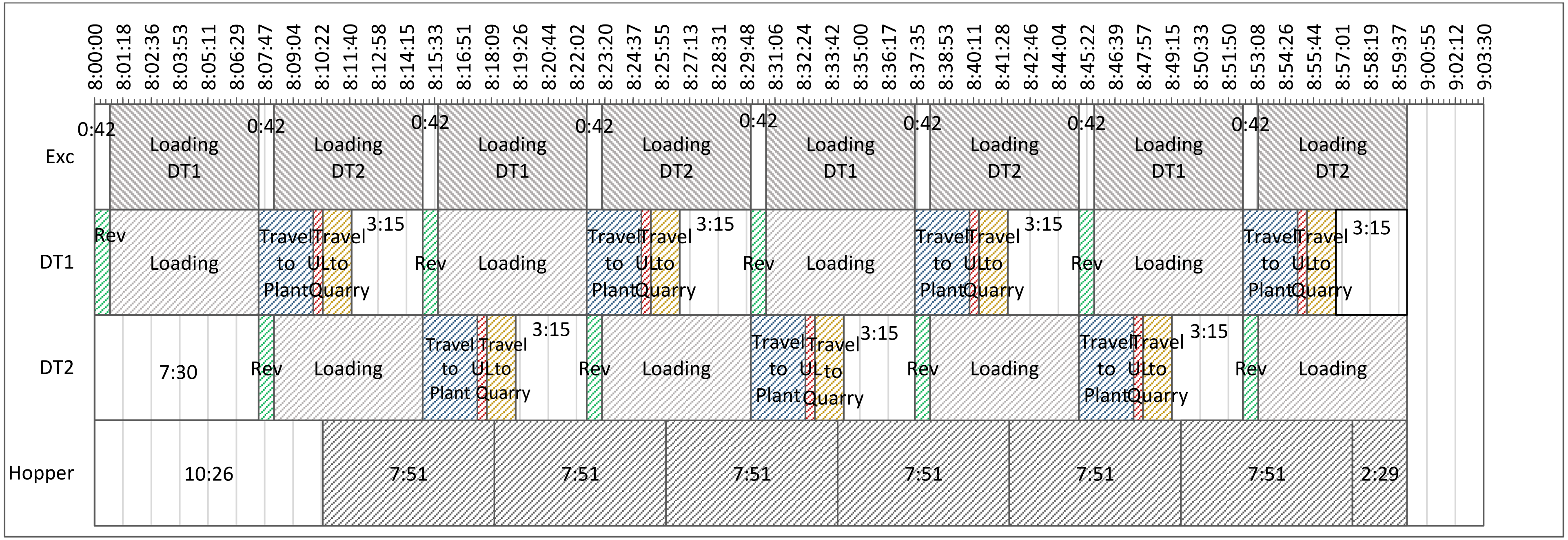
Plant No.01 Before Improving

Reversing	0:42	min
Loading	6:48	min
Traveling	2:30	min
Unloading	0:26	min
Traveling back	1:19	min
Plant	130	ton/hr
DT	17	ton
Excavator	150	ton/hr
Hopper	40	ton

Cycle Time	11:45		
	Loading waiting	Unloading waiting	waiting at hopper
DT1	13:00	0:00	0:00
DT2	9:45	0:00	0:00
Excavator	0:00		

Plant Idling 0:00 min

Production 107.39 ton

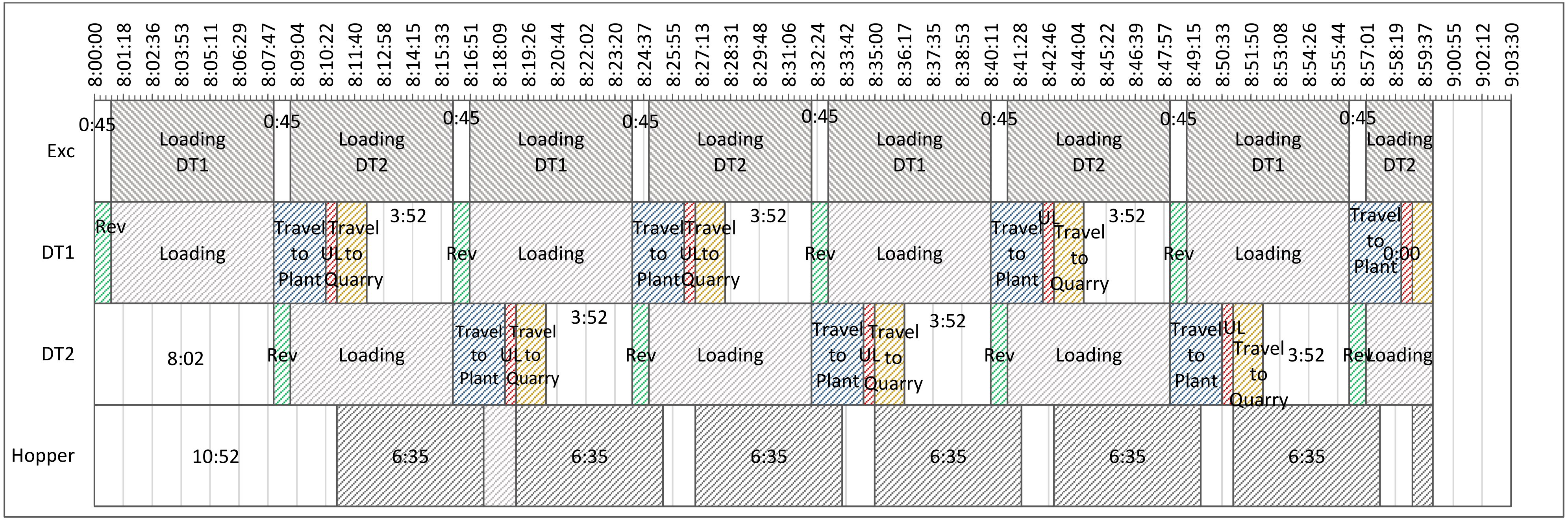


Plant No.01 After Improving

Reversing	0:45	min
Loading	7:17	min
Traveling	2:20	min
Unloading	0:30	min
Traveling back	1:20	min
Plant	155	ton/hr
DT	17	ton
Excavator	140	ton/hr
Hopper	40	ton

Cycle Time	12:12		
	Loading waiting	Unloading waiting	waiting at hopper
DT1	11:36	0:00	0:00
DT2	11:36	0:00	0:00
Excavator	0:00		

Plant Idling 8:44 min
Production 104.37 ton



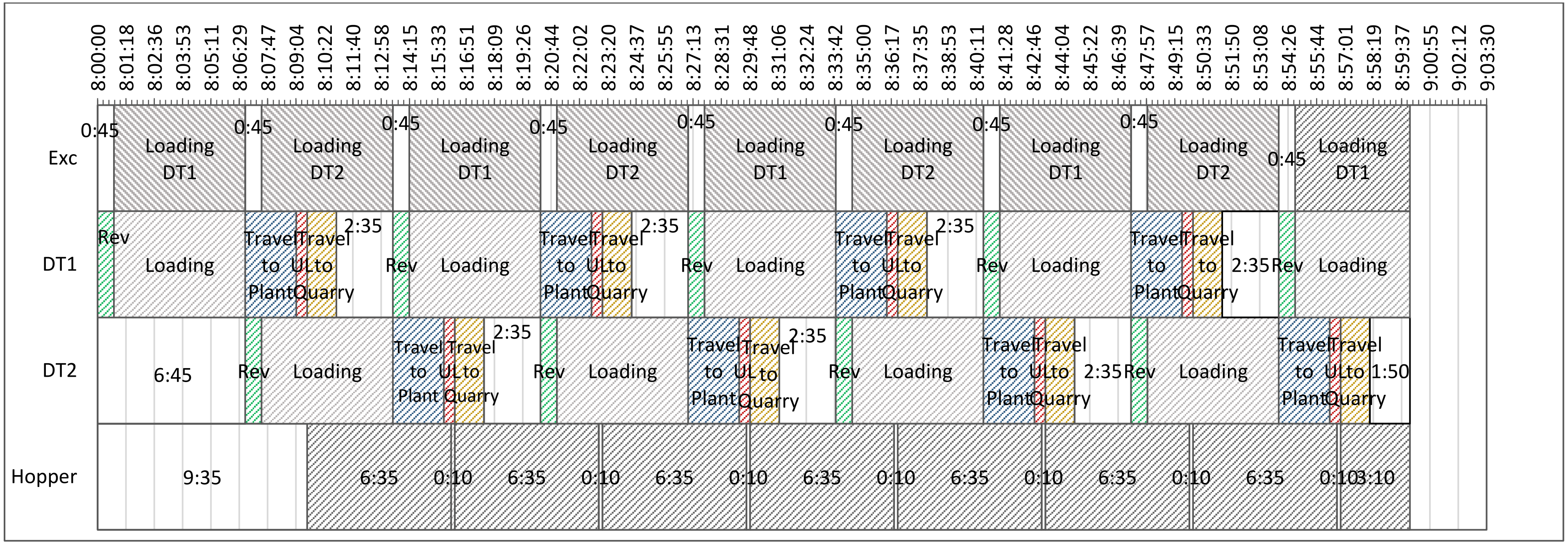
Plant No.02 Before Improving

Reversing	0:45	min
Loading	6:00	min
Traveling	2:20	min
Unloading	0:30	min
Traveling back	1:20	min
Plant	155	ton/hr
DT	17	ton
Excavator	170	ton/hr
Hopper	40	ton

Cycle Time	10:55		
	Loading waiting	Unloading waiting	waiting at hopper
DT1	10:20	0:00	0:00
DT2	9:35	0:00	0:00
Excavator	0:00		

Plant Idling 1:11 min

Production 127.18 ton



Plant No.02 After Improving

APPENDIX B

Annex B01: Monthly Production Sheet

PRODUCTION SEPTEMBER 2015

PLANTS	THIS MONTH			CUMULATIVE		STOCK PILE BALANCE	
PANNALA PLANT							
ASPHALT PLANT		3,967.50	ton	492,938.21	ton		
CRUSHER PLANT (BOULDERS)		7,625.95	ton	991,324.18	ton	-	ton
	Supplied :-	7,625.95	ton				
Cone Crusher		2,259.95	ton	117,092.53	ton		
BOPITIYA PLANT							
ASPHALT PLANT		1,796.64	ton	398,365.91	ton		
CRUSHER PLANT (BOULDERS)		14,594.53	ton	909,623.60	ton	1,110.67	ton
	Supplied :-	5,182.43	ton				
QUARRY PRODUCTION		1,126.69	ton				
DECANTING PLANT 01		422.00	drums	62,612.00	drums		
DECANTING PLANT 02		814.00	drums	67,750.00	drums		
DECANTING PLANT 03		1,036.00	drums	65,389.00	drums	Balance = 2,640 drums	
MAHIYANGANAYA PLANT							
ASPHALT PLANT		3,284.24	ton	76,448.26	ton		
CRUSHER PLANT		1,482.96	ton	137,457.91	ton	604.44	ton
	Supplied :-	1,854.14	ton				
BELIATTA PLANT							
CRUSHER PLANT			ton	17,388.87	ton		

Total Production of the month:-	**Asphalt**	9,048.38	ton
	Crusher	25,963.39	ton
	Decanting	2,272.00	drums

Wearing	=	5,876.89 ton
Binder	=	3,165.47 ton
Pre mix	=	6.02ton

Keangnam (Hot bitumen) = 0 ton

Annex B02: Monthly Labour Involvement

NEM CONSTRUCTION (Pvt) LTD	Record No	5
MONTHLY COSTING REPORT - SEPTEMBER ~2015	Page No	
BOPITIYA SITE		

BOPITIYA SITE STAFF SALARY SHEET

Administration

permanent

No	Service No	Name	Designations	2015-August Amount
1	1965	A.M.S.B.Amarasooriya	Project Manager	25,000.00
2	2152	W.I.U.S.Wickramasingha	Mining Engineer	25,000.00
3	2444	Y.H.P.S.M.Yapa	Mining Engineer	28,320.00
4	733	C.M.R.C.Fernando	Operation Office	45,700.00
6	2198	A.I.P.M.Saranga	Accounter	38,410.00
7	2295	H.M.A.P.Dissanayake	Monitering Assistant	43,030.00
9	2712	S.A.M.N.K.Sundarapperuma	Safety Officer	28,520.00
10	2413	H.D Somapala	Helper (Office)	24,910.00
11	1988	K.A.L.Silva	Plant Machanic	45,200.00
	Allowances			343,375.00
	Total Amount			**647,465.00**

Casul Wages

				1~15	15~31	Total
1		H.M.C.Chamika	W/B	10,700.00	10,200.00	20,900.00
2		U.T.Prabath	W/B	9,850.00	9,300.00	19,150.00
3		J.A.C.Jewantha	W/B	6,375.00	6,225.00	12,600.00
4		M.A.Premasiri	kitchen	9,350.00	11,600.00	20,950.00
5		P.K.Ruwan Kumara	kitchen	10,500.00	10,450.00	20,950.00
6		R.S.Rajapaksha	off. Helper	11,900.00	6,200.00	18,100.00
	Total Amount					**112,650.00**

Stores

permanent

17	1686	S.P.J.Bandara	Stores Keepr	43,150.00
18	1856	H.M.P.C.Heratha	Stores Assistant	29,900.00
19	2302	K.S.Buddika	A.S.K	39,650.00
20	2412	V.R Samarathunga	Helper	30,780.00
22	2585	S.M.C.J.Samranayaka	Stores Assistant	30,300.00
	Total Amount			173,780.00

Crusher

permanent

91	1991	H.B.M.N.Karunarathna	Crusher Plant Operat	37,940.00	77,310.00	
92	2042	D.M.Jayathissa Banda	Crusher Plant Operat	39,370.00		
93	2418	W.G.N.A.Gunasekara	C.Helper	23,140.00		
94	2145	R Chandana	Welder	32,120.00	Welder Haff Add Asphalt Pla	
95	2144	K.M.N.N.Kumara	Welder	32,200.00	64,320.00	32,160.00
96	1989	W.M.Anura Kumara	Electrician	34,110.00		
97	2628	K Marasingha	Helper (Electrician)	31,270.00	Electrician Haff Add Adminis	
98	2795	B.P.Dumal Harishchandra	Helper (Electrician)	36,220.00	101,600.00	50,800.00
	Total Amount			266,370.00		

Casul Wages

99		R.M.Anuruddha	Helper	8,750.00	9,700.00	18,450.00
100		B.G.Wasantha	Helper	14,600.00	9,850.00	24,450.00
101		S.A.Aasoka Jayaveera	Helper	5,550.00	4,600.00	10,150.00
102		U.H.C.Ruwan	Helper	9,500.00	13,300.00	22,800.00
103		A.P Indika	Helper	10,400.00	12,450.00	22,850.00
104		W.J. Kasun deshapriya	Helper	9,200.00	12,450.00	21,650.00
105		w.m.Ajith hemantha	Helper	12,350.00	10,050.00	22,400.00
106		D.S.S.laksita	Helper	10,850.00	10,800.00	21,650.00
107		K Nevil Cristoper	Helper	10,550.00	6,850.00	17,400.00
108		M.M.S.Kumara	Helper	12,200.00	14,350.00	26,550.00
	Total Amount					**208,350.00**

231,490.00

Annex B03: Monthly Machinery Involvement

NEM CONSTRUCTION (Pvt) LTD
MONTHLY COSTING REPORT - SEPTEMBER ~2015
BOPITIYA SITE

Record No	6
Page No	

Bopitiya Plant Machinary & Vehicles Salary Distribution Sheet

Machine No	QURRY		CRUSHER PLANT		ASPHALT PLANT		From St/pla.(6 *9)		Quarry Cle..ring		DECANDIG PLANT-02		Other		Total	
	Hr	Salary	Hr	Salary	Hr	Salary	Hr	Salary	Hr	Salary	Hr	Salary	Hr	Salary	Total Hrs	Salary
227-3554	-	-	-	-		-	-	-	-	-		-	-	-	-	-
227-3555	-	-	-	-		-	-	-	-	-		-	-	-	-	-
227-3551	-	-	-	-		-	-	-	-	-		-	-	-	-	-
68-2485	4.50	1,435.05	0.50	159.45		-	15.00	4,783.50	-	-		-	-	-	20.00	6,378.00
LD-2963	4.50	1,435.05	2.00	637.80		-	17.67	5,634.96	-	-		-	-	-	24.17	7,707.81
68-2484	-	-	-	-		-	-	-	-	-		-	-	-	-	-
68-2486	-	-	4.67	1,489.26		-	21.00	6,696.90	-	-	-	-	-	-	25.67	8,186.16
LD-2968	4.50	1,435.05	2.33	743.04		-	32.17	10,259.01	-	-		-	-	-	39.00	12,437.10
	13.50	***4,305.15***	***9.50***	***3,029.55***	**-**	**-**	***85.84***	***27,374.37***	**-**	**-**	**-**	**-**	**-**	**-**	***108.84***	***34,709.07***
950G W/L 17		-		-		-		-		-		-		-	-	-
928G W/L 19		-		-		-		-		-		-		-	-	-
924G W/L 22	-	-	116.50	57,135.10	22.00	10,789.46		-		-		-	1.50	735.65	140.00	68,660.21
924G W/L 23	-	-	-	-	-	-		-		-		-		-	-	-
924 G W/L 20		-	32.00	15,693.76	7.00	3,433.01		-		-		-		-	39.00	19,126.77
Loader Ope.Salary		**-**		***72,828.86***		***14,222.47***	**-**	**-**	**-**	**-**	**-**	**-**	***1.50***	***735.65***	***179.00***	***87,786.98***
HE-29	61.00	13,859.74		-		-		-		-		-		-	61.00	13,859.74
HE-20		-		-		-		-		-		-		-	-	-
HE-36		-		-		-		-		-		-		-	-	-
He-38	14.00	3,180.92	7.00	1,590.46		-	28.00	6,361.85	4.00	908.84		-		-	53.00	12,042.07
HE-36		-		-		-		-		-		-		-	-	-
HE-32	2.00	454.42	28.00	6,361.85	-	-	50.00	11,360.44		-		-	2.00	454.42	82.00	18,631.13
HE-33		-		-		-		-		-		-		-	-	-
HE-8		-		-		-		-		-		-		-	-	-
Excavator Ope. Salary		***3,635.34***		***7,952.31***		**-**		***17,722.29***		***908.84***	**-**	**-**		***454.42***	***196.00***	***44,532.94***
BOB CAT -7	0.50	157.67	5.00	1,576.67	1.50	473.00		-		-	4.00	1,261.33	1.00	315.33	12.00	3,784.00

Annex B04: The Production Cost of Crusher Section

NEM CONSTRUCTION (Pvt) LTD						Record No	11
MONTHLY COSTING REPORT - SEPTEMBER ~2015						Page No	
BOPITIYA SITE							
CRUSHRING COST							
DESCRIPTION	**UNIT**	**QTY**	**RATE**	**AMOUNT**	**SUB TOTAL**	**% of Total Cost**	**UNIT COST Rs. / Ton**
MANPOWER COST							
Plant Engineer	Nos						
Plant Operator	Nos	3		77,310.00		2.00%	5.30
Helpers	Nos	8		231,490.00		6.00%	15.86
Loader Operator	Nos			72,828.86		2.00%	4.99
Water Bowser	Nos			43,555.00			
Ten Wheel driver	Nos			3,029.55			
Excavators	Nos			25,674.60			
Welders	Nos	2		32,160.00		1.00%	2.20
Electrician	Nos	2		50,800.00		1.00%	3.48
ETF & EPF (15%)						0.00%	-
					536,848.01	**12.00%**	**36.78**
PLANT DIESEL COST							
Generator -365	Hr	92.80	750.00	69,600.00		2.00%	4.77
Diesel	Lts	2,813.00	95.00	267,235.00		7.00%	18.31
Generator -410	Hr		750.00	-		0.00%	-
Diesel	Lts		95.00	-		0.00%	-
Generator -500	Hr	168.50	750.00	126,375.00		3.00%	8.66
Diesel	Lts	7,348.00	95.00	698,060.00		18.00%	47.83
Plant Diesel Cost					**965,295.00**	**24.00%**	**66.14**
					195,975.00	**5.00%**	**13.43**
MACHINE COST						**0.00%**	**-**
9240 Wheel Loader -23	Hr		1,900.00	-		0.00%	-
Diesel	Lts		95.00	-		0.00%	-
924 G Wheel loaer -22,	Hr	116.50	1,900.00	221,350.00		6.00%	15.17
Diesel	Lts	1,640.99	95.00	155,894.05		4.00%	10.68
924 G Wheel loaer -20	Hr	32.00	1,900.00	60,800.00		2.00%	4.17
Diesel	Lts	356.11	95.00	33,830.45		1.00%	2.32
Excavators	Hr	35.00	2,100.00	73,500.00		2.00%	5.04
Diesel for Excavators	Lts	626.60	95.00	59,527.00		2.00%	4.08
Ten Wheelers	Hr	9.49	1,700.00	16,133.00		0.00%	1.11
Diesel	Lts	64.51	95.00	6,128.45		0.00%	0.42
LT-14	Hr	4.80	300.00	1,440.00		0.00%	0.10
Diesel	Lts	54.00	95.00	5,130.00		0.00%	0.35
PA-5347(W/B)	Hr			25,000.00		1.00%	1.71
Diesel	Lts	44.00	95.00	4,180.00		0.00%	0.29
47-0224 (w/B)	Hr			25,000.00		1.00%	1.71
Diesel	Lts	35.00	95.00	3,325.00		0.00%	0.23
WG-13	Hr		500.00	-		0.00%	-
Diesel	Lts		95.00	-		0.00%	-
Diesel For Water Pumps	Lts	28.00	95.00	2,660.00		0.00%	0.18
BOB CAT-7	Hr	5.00	900.00	4,500.00		0.00%	0.31
Diesel	Lts	33.74	95.00	3,205.30		0.00%	0.22
6 x9 Loading & Transport Cost				545,058.56			
					1,246,661.81	**32.00%**	**85.42**
PLANT COST						0.00%	-
Electricity Expenses						0.00%	-
Material Cost				100,765.69	100,765.69	3.00%	6.90
ADMINISTRATION COST				899,336.43	**899,336.43**	23.00%	**61.62**
Total Running Cost					**3,944,881.94**	**91%**	**249.97**
Crusher Production (Ton)			**Ton**		**14,594.53**		**14594.53**
Running Cost Of Unit from Crusher Plant			Rs./Ton		**270.30**		

……………………………. PREPARED BY	………………………………………… CHECKED BY	……………………………………………. APPROVED BY
DATE	DATE	DATE

APPENDIX C

Annex C01: Flow Chart –Stores Management System of Organization

FLOW CHART	ACTIVITY OR OPERATION	CONTROL PARAMETERS	RECORD/DOCUMENT	RESPONSIBLE OFFICER
1 1	(1)Receiving Material Requisition Form From Site	Authorized by PM		PM, SM
2	(2)Sending MRF to Procurement Department to Check Availability	Followed by MRF		PM Estimator
3	(3)Sending samples from sample room/ technical literature/ for approval if necessary	Contractor document details available quantity	Delivery Advice of Dispatch	PM Estimator
4	(4)If not available - sending MRF to Procurement Managers(MPS)	Ex.Stock	1st copy	SK
5	(5)Receiving Purchase Order from Procurement Department			MPS, SK
6	(6)Fax to the Supplier		PO	Estimator
7	(7) Send the vehicle to collect the items		PO	SK
8	(8)If materials were not received to H/O		Pending material summary	SK
9	(9)Receiving items to stores		Dispatch Note, Invoice, PO	SK
10	(10)Raising items to stores		GRN, DA.	SK
11	(11)Sent to the site		Gate Pass, Material Daily Receiving Summary, Issuing Summary	SK
12	(12)Get original GRN from site			Data Entry Operator (Executive)
13	(13)Send the Invoice and GRN to Procurement division		Invoice, PO, Copy GRN	SK
14	(14)Monitoring monthly budget site wise			

Annex C02: Material Requisition Form

MATERIAL REQUISITION FORM

NEM

NAME OF PROJECT ______________________ DATE ______________

NO	ITEM	LAST REQUISITION NUMBER & DATE		BALANCE AT LAST REQUISITION DATE	QTY RECEIVED FROM LAST REQUISITION	QTU USED	BALANCE AT SITE	THIS REQUEST		HEAD OFFICE USE ONLY
								QTY	EXP DATE	

STORE KEEPER ______________________ PROJECT MANAGER ______________________

Annex C03: Purchase Order

NEM CONSTRUCTION (PVT) LTD.

No.629, Baseline Road, Colombo 09.

Telephone : +94-11-2671814 / 11-2672071 Fax : +94-11-2685132 Email. nemcons@sltnet.lk

PURCHASE ORDER

To :

Co.Reg.No:
Date:
Purchase Order No:
MRF No:

Delivery Instructions :-

No.	Item Description	Unit	Qty	Rate (Rs.)	Amount (Rs.)
					-
	Sub Total				-
	TOTAL				**-**

Please acknowledge receipt of our order.The acceptance and execution of this order by you implies that you have accepted the above conditions

Please quote this Purchase Order number in your invoice

…………………………………………

Purchasing Manager

Annex C04: Goods Received Note

NEM CONSTRUCTION (PVT) LTD. 17, Minuwangoda Road,
Ekala, Ja-Ela

Form No. Sr/02
G.R Note
Work Site ....
....

Supplier .... Purchase Date ....
Our Purchase Order No .... Date .... CASH/CREDIT
Supplier Invoice No ....

Item No	Description	Code No	Qty Received		Value			Remarks
			Unit	Qty	Price	Rs.	Cts.	
					TOTAL			

I Certify that the receipt of goods described above is in good condition and order / as per specification in purchase order as stated in remarks column.

....
Store Keeper

....
Payment Approved

Not Supplied/ Leakages / Returns / Damages noted for action

....
Supplier Office

....
Book Keeper

Annex C05: Advice of Dispatch

NEM CONSTRUCTION (PVT) LTD

From: No ST/05

17, Minuwangoda Road,

No : ....

Ekala Ja-Ela

Date: ....

Tel : 2233371

ADVICE OF DISPATCH

Work Site ....

To ....

From ....

The follwing quantities of goods dispatched by vehicle No: on ....

Please acknowledge receipt of same on the green copy attached.

Item No	Indent No	Description	Unit	Qty	Unit Price	Value		Remarks
						Rs.	Cts.	

Document Ref : Transport Contractor

Issed by

....

For NEM(pvt) ltd

Checked by

....

Received by

....

Storekeeper

CARRIER'S STATEMENT

Examined the above and received in good condition

ඉහත සඳහන් බඩු පරීක්ෂා කර බාර ගතිමි.

....

රියදුරු / සහයක අත්සන

Annex C06: Stock Book

190

STOCK BOOK

Date	Description	In. ro No.	Receive	Issued	Balance	

Annex C07: Database Report (Raw Material Supply to the Plant)

NEM CONSTRUCTION (PVT) LTD

Material Overview for a Project

Ledger : Boulders

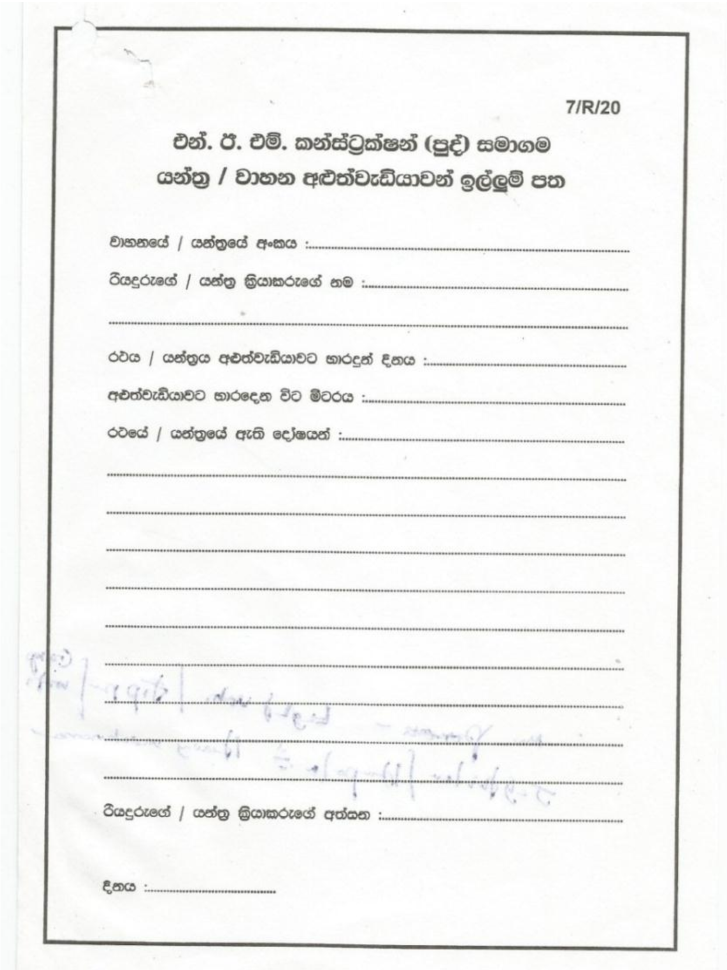
Project Code : Crusher Plant -02 (Boulder Crusher -Pannala)

Date From : 01-Sep-15 **Upto :** 30-Sep-15

Date	PO NO	GRN NO	SRN NO	MTN/ MRN NO	Project / Supplier	Rate	Debit Quantity	Amount Debit (Rs)	Credit Quantity	Amount Credit (Rs)
11/01/14					Nuw an Construction		475.83		0.00	0.00
11/01/14					Asphalt Plant -Stock(Pannala)		154.26		0.00	0.00
11/03/14					Nuw an Construction		325.29		0.00	0.00
11/03/14					Asphalt Plant -Stock(Pannala)		97.44		0.00	0.00
11/10/14					Asphalt Plant -Stock(Pannala)		453.48		0.00	0.00
11/11/14					Asphalt Plant -Stock(Pannala)		551.38		0.00	0.00
11/12/14					Asphalt Plant -Stock(Pannala)		458.45		0.00	0.00
11/13/14					Asphalt Plant -Stock(Pannala)		421.31		0.00	0.00
11/14/14					Asphalt Plant -Stock(Pannala)		719.13		0.00	0.00
11/15/14					Asphalt Plant -Stock(Pannala)		850.51		0.00	0.00
11/16/14					Asphalt Plant -Stock(Pannala)		181.22		0.00	0.00
11/17/14					Asphalt Plant -Stock(Pannala)		885.83		0.00	0.00
11/18/14					Nuw an Construction		684.19		0.00	0.00
11/18/14					Asphalt Plant -Stock(Pannala)		120.71		0.00	0.00
11/19/14					Nuw an Construction		708.96		0.00	0.00
11/19/14					Asphalt Plant -Stock(Pannala)		138.38		0.00	0.00
11/20/14					Asphalt Plant -Stock(Pannala)		47.71		0.00	0.00
11/20/14					Nuw an Construction		482.55		0.00	0.00
										0.00
					Total		7,756.63			
					Balance		7,756.63	0.00	0.00	0.00

APPENDIX D

Annex D01: Job Request Form



7/R/20

එන්. ඊ. එම්. කන්ස්ට්‍රක්ෂන් (පුද්) සමාගම

යන්ත්‍ර / වාහන අළුත්වැඩියාවන් ඉල්ලුම් පත

වාහනයේ / යන්ත්‍රයේ අංකය :..........

රියදුරුගේ / යන්ත්‍ර ක්‍රියාකරුගේ නම :..........

....

රථය / යන්ත්‍රය අළුත්වැඩියාවට භාරදුන් දිනය :..........

අළුත්වැඩියාවට භාරදෙන විට මීටරය :..........

රථයේ / යන්ත්‍රයේ ඇති දෝෂයන් :..........

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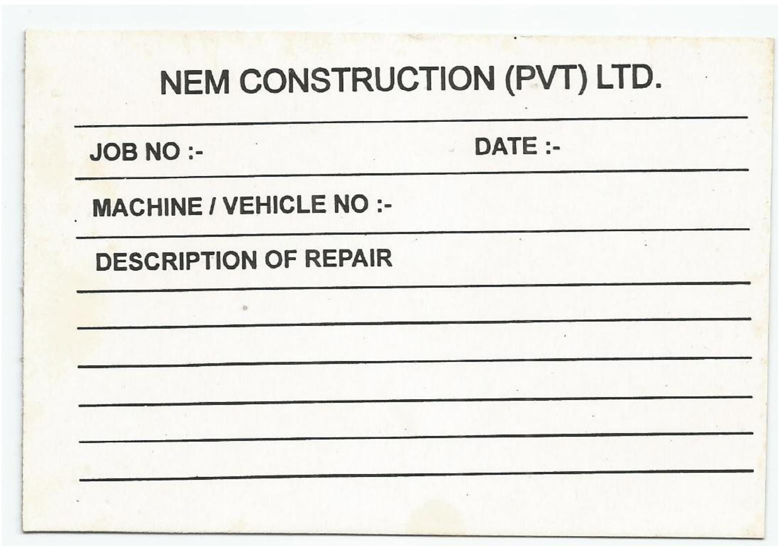
රියදුරුගේ / යන්ත්‍ර ක්‍රියාකරුගේ අත්සන :..........

දිනය :..........

Annex D02: Job Card



NEM CONSTRUCTION (PVT) LTD.

JOB NO :- DATE :-

MACHINE / VEHICLE NO :-

DESCRIPTION OF REPAIR

Annex D03: Work Order Form

NEM CONSTRUCTION (PVT) LTD.

WORK ORDER FORM

Work Order No.

Job No :

Date of job Received

Date of Commencement

Date of Completion

01. ***Request for Service / Repair / Activity***

a) Machine / Vehicle / Item / Activity Identification No.

b) Meter reading

c) Name of the drive / operator

d) Brief description of the repair requested

e) Diagnosis of the fault

Mechanical Officer   Date

02. ***Job Card***

a) Job No

c) Date of commencement

b) Date of job Received

d) Date of completion

e) Description of the work attended to

f) Final Inspection done by : Name   Date

I certify that all necessary repairs have been completed and machinery / Vehicle tested and found to be OK

Mechanical Officer   Date

03. ***Labour Cost***

	D	A	T	E				Total Days Hours	Rate	Amount (Rs)
Mechanic										
Welders										
Lathemen										
Electricians										
Tinkers										
Painters										
Services Men										
Tyre Fitters										
Supervision										
									TOTAL	

MRN Nos.

04. ***Materials used***

Date	Part No	Material / Description	Qty	Amount (Rs)

Checked and certified correct by

Mechanical Manager

Date

05. ***Repair and maintenance cost summary***

a) Total spares cost Rs. ....

b) Total material cost Rs. ....

c) Total labour cost Rs. ....

d) Total machine & vehicle cost Rs. ....

e) Other expense Rs. ....

Total Cost for the job Rs. ....

Mechanical Officer

Date

Annex D04: Database Format (Monthly maintenance & Repair cost of a Plant)

NEM CONSTRUCTION (PVT) LTD

Repair History

Vehicle No : LE - 7783

Job No	Repair Type	Duration	Material Used	Labour Cost	Sparepats Used	Vehicla & Machinery Used	Other Expenses	Total
2015(01/13)	Mechanical		1,255.00	7,125.00	1,960.00	1,834.50		12,174.50
2015(02/28)	Mechanical		4,006.00	22,103.00	7,675.00	7,862.70		41,646.70
						Total		53,821.20