LEAN STRATEGIES TO MINIMIZE WASTE IN SRI LANKAN QUARRY INDUSTRY

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Degree of Master of Science in Project Management

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Thesis/ Dissertation submitted in partial fulfilment of the requirements for the degree Master of Science in Project Management

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Signature of the supervisor: Date:

DEDICATION

This dissertation is gratefully dedicated to my father and mother for making me who I am, and wife for supporting me all the way!

ACKNOWLEDGEMENT

This dissertation would not have been possible without the support of so many people in so many ways. I owe a debt of gratitude to each and every one who spent their valuable time and effort and to all who shared their knowledge and professional experience.

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Furthermore, I wish to express my greatest appreciation to the industry professionals and all the interviewers for their valuable support to success this dissertation.

Finally, I take this opportunity to thank my family and batch mates for their emotional and moral support.

ABSTRACT

Lean strategies to minimize waste in Sri Lankan quarry industry

Aggregates product is one of the main contributors to the construction industry. According to the GSMB records, the total annual production of crushed and broken rock is about 10 million cubic meters. Due to the rapid increase of construction industry, the demand for the rock is also increasing and it will help to increase the number of metal quarries in the country. Therefore, there is a need to enhance quantity and productivity of process in industrial quarry projects.

It is very difficult to find a systematically well-developed quarry although there is a high demand for aggregate product in Sri Lanka. It is observed that there are many non – value adding activities (waste) in their processes which hinder the quarry performance. Therefore, there is a need to implement concept such as lean philosophy in order to eliminate or minimize waste and to optimize quarry operation.

Accordingly, aim of this research is to identify lean strategies to minimize waste in Sri Lankan quarry industry.One of the objectives of this study was to identify lean concept and main industrial waste. This objective was successfully achieved through a comprehensive literature survey and end of the literature review the conceptual model for the study was developed.

Multiple case study method under qualitative research approach was selected as the most suitable research method for this study. Three industrial quarry sites were selected under the multiple case study design. Data collection for the case study was based on semi structured interviews based on the open ended questions to enhance the richness of the information collected. Data were analyzed adopting content analysis, tables and cognitive mapping techniques.

Cognitive map was developed for all identified factors affecting waste in Sri Lankan aggregate mining industry under main eight waste which are Over Production, Waiting/ Delay, Unnecessary Transportation, Unnecessary Processing, Excess Inventories, Unnecessary Movement/ Motion, Defects, Underutilised People . The proposed strategies for each factor were linked to relevant lean strategy by considering literature review and desk study. Finally, initially developed conceptual model was modified to prepare a framework to minimize waste (non-value adding activities) in Sri Lankan quarry industry by using lean strategies as the final outcome of the research. Accordingly TPM, JIT, Bottleneck Analysis, PDCA, 5S, Kaizen, TQM, Poka-Yoke, Jidoka were identified as key lean strategies to minimizes main eight waste in quarry industry.

Key words: Aggregate mining Industry/ Quarry Industry, Lean Concept, Waste

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviation	Description
ABC	Aggregate Base Course
AIV	Aggregate Impact Value
AML	Artisanal Mining Licence
ANFO	Ammonium-Nitrate with Fuel Oil
FI	Flakiness Index
FPS	Ford Production System
GSMB	Geological Survey and Mines Bureau
IML	Industrial Mining Licence
ISEE	International Society of Explosive Engineers
JIT	Just in Time
LAAV	Loss Angelies Abrasion Value
NVAA	Non Value Added Activities
PDCA	Plan-Do-Check-Act
PPE	personal protective equipment
SG	Specific Gravity
TPM	Total Productive Maintenance
TPS	Toyota Production System
TPSBH	Toyota Production System Basic Handbook
TQM	Total Quality Management
VSM	Value Stream Mapping

CHAPTER 01

1. INTRODUCTION

1.1 Background

Mining industry is one of the oldest and economically important industries in the world (Slack, 2010).Economically viable mineral and metal ore deposits are distributed worldwide, therefore large companies of global mining industry are scattered in both developed and developing countries (Shapiro, et al., 2007).

According to the rank by market capitalization of major global mining companies in 2011 from Forbes magazine (10/05/2011), there were twenty (20) largest mining companies in the world located in eleven (11) different countries. Those are UK, Canada, USA, China, Australia, Brazil, India, Japan, Mexico, Russia and Switzerland. Major mining companies are based on the gold, boxite, platinum, copper, zinc, nickel, diamond, aggregates, coal, petroleum, iron, industrial minerals, uranium, potash, natural gas, molybdenum, lead, silver, phosphate, cobalt and germanium mines (Shapiro, et al., 2007). There are two basic types of mines, i.e. underground and open pit. The above minerals are excavated from one of these methods (International Society of Explosive Engineers (ISEE), 1999).

In recent years, Western mining companies have faced increasing competition from Chinese companies, which have been aggressively seeking minerals to feed China's roaring economy. Chinese companies have been active in Latin America, Asia and, in particular Africa (Slack, 2010).

Sri Lanka is reasonably endowed with industrial minerals but not with metallic and energy minerals. However, the presence of hydrocarbons within an offshore exploration tenement in Mannar basin has been reported recently and the detailed exploration is in progress (Geological Survey and Mines Bureau (GSMB), 2012). The major minerals resources in Sri Lanka include graphite, mineral sands (ilmenite, rutile, zircon), feldspar, brick and tile clay, ball clay, kaolin, apatite (rock phosphate), silica sand, quartz, mica, Miocene limestone, calcite, dolomite, dimension stone, crushed and broken rock, gemstone, seashells (Herath, 2003). Industrial minerals such as graphite, mica, mineral sands and quartz are mainly export-oriented mineral commodities in Sri Lanka. All industrial minerals except graphite are mined in quarries or surficial pits by open-cast method. The only two underground working mines for graphite are located at Bogala and Dodangaslanda (GSMB, 2012).

Except for the mines operated by the public sector companies such as Eppawala Apatite Mine, Mineral Sands Mines at Pulmoddai and Kahatagaha Graphite Mine, the other mines are mainly owned by private sector (GSMB, 2012).

Consequent to the expansion of mineral based industries during the past few decades, there is a substantial growth in exploitation of minerals (GSMB, 2012). Among the above mentioned industrial mines, aggregates product is one of the main contributors to the construction industry.

Broken or crushed stone (metal/aggregates) is obtained by quarrying from open pit or hillside excavations in the rock outcrops of an area (Herath, 2010). These are one of the most commonly available mineral resources in anywhere of the country and a basic raw material used by the construction industry. Different sizes of broken and crushed rocks are produced according to the requirements of building and construction industries (GSMB, 2012). According to the GSMB records, estimation based on the allowable monthly production limits for each category of licences, the total annual production of crushed and broken rock is about 9.8 million cubic meters.

According to the Mines and Minerals Act No.33 of 1992, there are main two categories of mining licences. Those are Artisanal Mining Licence (AML) and Industrial Mining Licence (IML). AML is based on the traditional mining method and for the metal quarries this is been operating in a very limited number of quarries. According to the GSMB records, total number of licenced metal quarries in operation is 2,209 up to end of 2011. About 95% of theses quarries are industrial types and only 5% is artisanal type. Further to the GSMB records over the years the numbers of AML quarries have been decreased and the IML quarries have been increased remarkably. Numbers of total metal quarries are also increased from 1709 to 2209 from year 2009 to 2011. Due to the rapid increase of construction industry, the demand for the rock is also increasing and it will help to increase the number of metal quarries in the country. Therefore, there is a need to enhance quantity and productivity of process in industrial quarry projects. Thus, this study is focus on aggregate mines among other types.

Quarry operation consists with a set of processes and they are same for all quarries(Rylander,2013). It is observed that there are many non – value adding activities in their processes which hinder the quarry performance. There is therefore a need to implement concept such as lean philosophy in order to eliminate or minimize non – value adding activities and to optimize quarry operation.

Lean principle is a predominant management philosophy in manufacturing industry. Toyota motor company is the leader in lean manufacturing techniques and has started to use during the 1950s -1960s. This is a performance-based process and focus on the elimination of waste or non-value added steps within the entire industry or organization (Mc Givern &Stiber,2014). Lean management also helps to increase quality, just in time of activities and decrease the production cost. There is a set of principles, tools and methods defined under the lean management (Rylander,2013).

Womack and Jones (2003) suggested five lean principles. Those are specific value, identify the value stream, flow, pull and perfection. Waste should be eliminated to make value flow (Andi et al., 2009). Shingo (1996) identified 7 wastes in lean principle. Those are;

1. Waiting
2. Over Production
3. Repair
4. Motion
5. Processing (over)
6. Inventory
7. Transportation

Recently this is developed as 7 + 1 waste due to addition of another type of waste namely “Human talent” (Andi et al., 2009).

Andi, Wijaya, R.Kumar and Kumar (2009) identified the issues and challenges of implementing lean principles into mining industry. According to the findings, lean principle can be successfully applied to the mining industry, but have to consider many issues and manage those in a smart way. Kippel, Petter and Antunes (2008), have practically show the benefit of implementing lean to the mining industry by their selected cases of two underground mining projects. Those are fluorspar mine and amethyst mine in Brazil. From this have been identified waste related to basic 7 wastes in lean principle. By minimizing identified waste they have achieved considerable increase in efficiency and quality of worker’s life. Therefore this research is a good example to understand the value of applying lean principle to the mining industry. Rosienkiewicz (2012) introduced the idea of adaption of Value Stream Mapping (VSM) Method to the mining industry and used that technique to identify the waste. Those researches based on the underground mining projects, and have not discussed about the open-pit mining projects.

Rylander (2013) has researched to identify waste in quarry operations by applying lean value stream mapping method. This has been discussed in a very narrow area of the quarry processes and has not given solutions to minimize waste. The researcher has only given the attention for finding waste in activities which are from transporting to crusher to delivering to customers in quarry operation.

1.2 Problem Statement

Lean principles have been applied in almost all type of manufacturing industries over the past 30 years since its origin from the Toyota production system and dramatically penetrate to the other industries like construction and mining (Andi et al., 2009). But in Sri Lanka, lean concept is not widely used yet (Danasooriya, 2011). Few garment factories like MAS Holdings and Hirdaramani Industries have already applied the lean principles and gain a significant amount of benefits (Weerasingha, 2010). Further, few researchers investigated on the application of lean concept to the Garment industry, Prefabrication production process and Construction industry

(Danasooriya, 2011).The application of lean in Sri Lankan construction industry still was not identified (Danasooriya, 2011).This concept is also not familiar to the Sri Lankan mining industry and there is a lack of research findings on the applicability of lean principle to minimize waste in Sri Lankan mining Industry.

It is very difficult to find a systematically well-developed quarry although there is a high demand for aggregate product in Sri Lanka. Waste such as time, cost, repair, inventory and transportation can be identified commonly in any quarry site. This significantly affect to the efficiency of quarry projects as well as construction projects that depend on those quarry sites. Therefore it is time to investigate the benefits of implementing lean principle to the quarry industry. This research intends to perform the above mentioned investigation along with the in-depth analysis of quarry operation and it will help to add the term of lean concept to the Sri Lankan mining industry.

1.3 Aim and Objectives

The aim of this research is to identify lean strategies to minimize waste in exploitation and processing stages of industrial quarry mining in Sri Lanka.

In order to achieve this aim following objectives have been set,

1. Review
    a) The lean concept and its application.
    b) The application of lean concept in mining industry.
    c) Main industrial waste/ non-value adding activities.
2. Investigate the factors affecting waste under main waste in exploitation and processing stages in the quarry mining process.
3. Identify lean strategies to minimize factors affecting waste in exploitation and processing stages in the quarry mining process.
4. Propose a framework to minimize non-value adding activities (waste) in exploitation and processing stages in quarry industry.

1.4 Methodology

A comprehensive literature survey was carried out by referring books, journals, articles, published research papers, unpublished dissertations and internet sources to identify the mining industries, its activities and issues, used techniques and methodologies. Above mentioned literature survey was also used to study the lean concepts, its applications and its current usage in mining industry. The common industrial waste/ non-value adding activities were identified from the literature survey.

Then an in-depth study was conducted adopting case study research approach. A case study is an empirical inquiry that investigates a contemporary phenomenon in depth within its real-life context, especially when the boundary between phenomenon and context are not clearly evident (Yin, 2009). A comprehensive studying of selected three metal quarry sites were carried out in order to identify factors affecting main waste /non-value adding activities in different processes in quarry industry and propose strategies to minimize them.

Collected data was analyzed with the use of content analysis. Finally, the strategies to minimize waste in Sri Lankan quarry industry were proposed.

1.5 Scope and Limitation

The research was limited to the Industrial Mining Licence (IML) category-A metal quarry projects in Western Province in Sri Lanka and it was limited to three cases due to time constraint.

All selected quarries were owned by the private sector, because only private sector involve to the industrial quarry projects/ aggregates mining industry in Sri Lanka.

The overall sequence of activities in metal quarry projects can be grouped into 6 stages, they are; Prospecting, Exploration, Development, Exploitation, Processing and Marketing (Andi et al., 2009). In this research scope will again be limited to the Exploitation and Processing stages and not discussed about Prospecting, Exploration, Development and Marketing stages.

1.6 Chapter Breakdown

Figure 1.1 shows the chapter breakdown, mapped with data collecting methods and objectives to be achieved at end of each chapter.

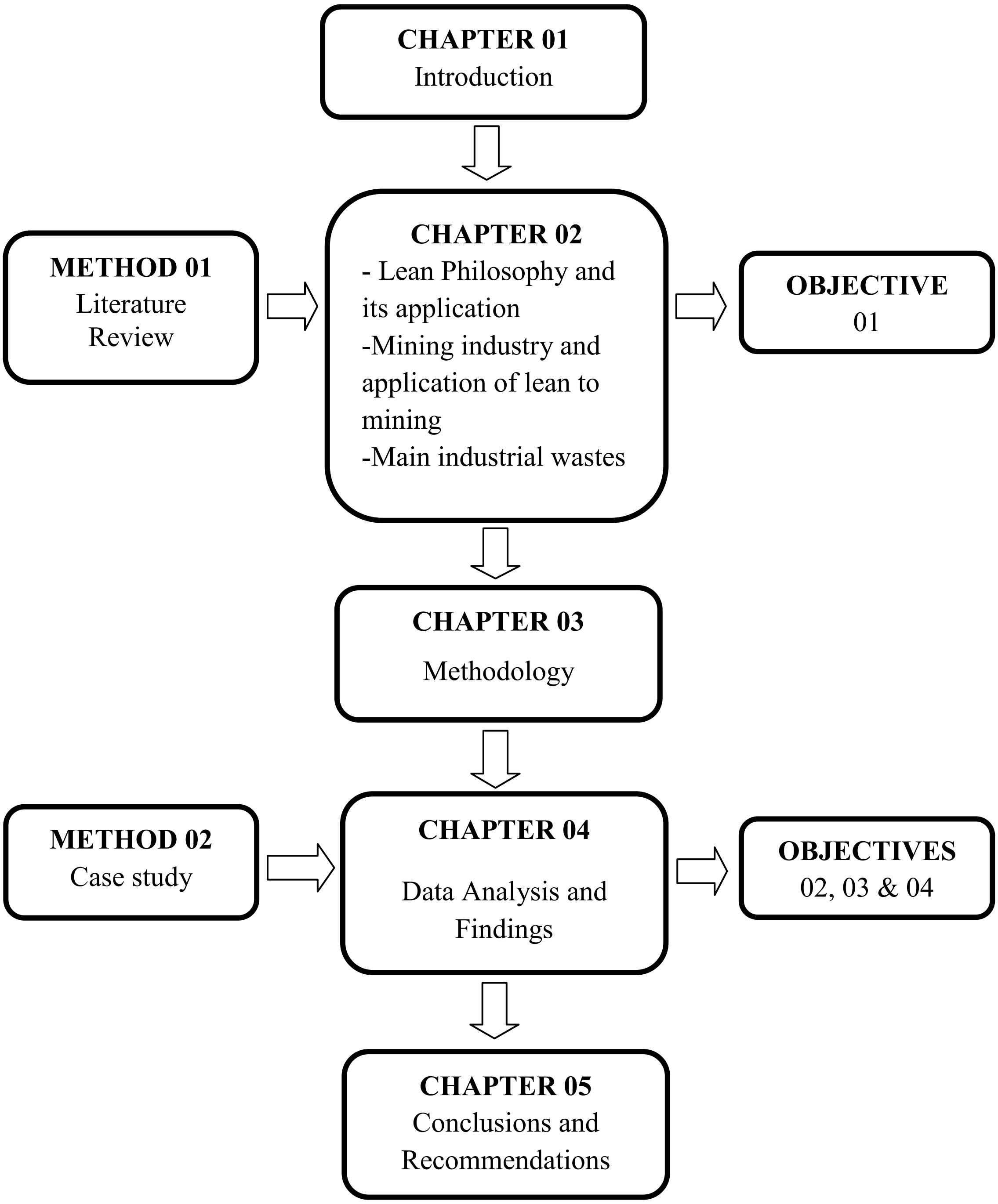

Figure 1.1: Chapter Breakdown

1.7 Summary

This chapter presents the introduction about global and local mining industry and application of lean concept to the mining industry. The research gap is emphasized in application of lean to the open-pit mining industry especially in Sri Lanka through the literature review. Research scope has limited to the industrial metal quarry mining projects and their limitations have discussed under the scope and limit. Further, the aim and the objectives of the research have been highlighted related to the application of lean to the industrial quarry projects and the chapter breakdown shows the overview illustrating the structure of the research.

CHAPTER 02

2. LITERATURE REVIEW

2.1 Mining Industry

Every industry in the world depends on the materials which extract from the earth. Hence Mining industry can have a huge impact on other trades of the world. "Minerals and metals are key to all services and infrastructure that are used by contemporary society: including shelter, food and water supply, sewage treatment, energy supply for a vast range of needs including heat and light, transportation, construction, manufacturing, education, health, communication, entertainment, the arts, tourism, and the vast range of associated consumer goods and services" (International Council on Mining and Metal (ICMM), Mining contribution to sustainable development October 2012).

Metallic minerals, nonmetallic minerals and fossil fuels are explored from the earth and these are needed for each and every trades and it is a continuous chain. Metallic ores consist with ferrous metals, base metals, precious metals and radioactive minerals. Iron, titanium, tungsten, manganese are the example for ferrous metals and copper, zinc, lead are the example for base metals. Precious metals are gold, silver and platinum. Uranium, thorium, radium are the example for radioactive minerals. Phosphate, potash, halite, sand, gravel, metal, limestones are not associated with metallic substances and those are non-fuel minerals called nonmetallic minerals and also called industrial minerals. Organic mineral substances such as coal, natural gas, coal bed, petroleum are utilized as fossil fuels (ICMM, Mining contribution to sustainable development October 2012).

With the advancement of technology, mining industry turned out be a high profit generating industry resulting movement of large number of companies into the industry. With the introduction of huge mining machineries to the mining operations product is improved. (ICMM, October2012).

Furthermore the discovery of Tungsten Carbide and industrial explosives helps to speed up mining activities which in return increase the production. To investigate and identify new resources advanced technologies like core drilling, seismic wave analysis, satellite images and arial photography are now being used. Companies were wise enough to increase their revenue parallel to the mining boom by improving their mining machinery performance and introducing new technologies and machineries to the industry (ICMM, October2012).

Modern mining is a large scale industry, which excavate massive open pits of about 4 km wide and 1 km deep. The part of rock that is excavated but unnecessary for the mining process is known as "Waste rock". When these rocks are dumped into piles it can be as high as 100m. In gold mining, gold is extracted from the surrounding rock by spraying a cyanide solution to the ore taken from the pits. The generated liquid by product known as "tailing" is dumped into large storage "ponds" of about 100m deep and 100m long (Slack, 2010).

With the recent value increase of minerals such as gold and copper, mining industry was able to build up a noticeable importance and influence. However governments and local communities that live near mine sites face wide range of challenges in economic, social and environmental management wise due to large scale industrial mining operations (Slack, 2010).

2.1.1 World Mining Industry

Mining industry is one of the oldest and economically important industries in the world (Slack, 2010).Economically viable mineral and metal ore deposits are distributed worldwide, therefore large companies of global mining industry are scattered in both developed and developing countries (Shapiro, et al., 2007).

According to the rank by market capitalization of major global mining companies in 2011 from Forbes magazine (10/05/2011), there were twenty (20) largest mining companies in the world located in eleven (11) different countries. Those are UK, Canada, USA, China, Australia, Brazil, India, Japan, Mexico, Russia and Switzerland. Major mining companies are based on the gold, boxite, platinum, copper, zinc, nickel, diamond, aggregates, coal, petroleum, iron, industrial minerals, uranium, potash, natural gas, molybdenum, lead, silver, phosphate, cobalt and germanium mines (Shapiro, et al., 2007).

In recent years, Western mining companies have faced increasing competition from Chinese companies, which have been aggressively seeking minerals to feed China's roaring economy. Chinese companies have been active in Latin America, Asia and, in particular Africa (Slack, 2010).

BHP Billiton, Rio Tinto and Vale were some of the mining companies that acquire a lion's share in market value in 2014. The other largest mining companies in revenue are China Schenhua, Xstrata, Angalo American, Barrick Gold, CVRD, India Potashcorp, Phelps Dodge and Mitsui(Annual report SEC Filings company cited Shapiro 2007;Forbes magazine 10th May 2011;Slack,2010; Statista, 2014).

These larger companies are clustered by thousands of small companies with small number of projects. Since the larger company is the one which has the greater capacity to actually mine the deposit, these small companies tries to sell the rights of the projects to the larger company by doing the opening work at the mine site such as exploration and feasibility studies (Slack, 2010).

Bingham Canyon located in US, is the deepest open pit mine in the world, has depth of more than 1.2 km, width of approximately 4 km up to end of 2012 (Figure 2.1 Left). Ownership of the mine is to the Rio Tinto company which has been in operation since 1906. Production of Kennecott Copper mine or Bingham Canyon are, 179,317 tons of copper, 270,200 ounces of gold, 2.4 million ounces (Moz) of silver and 20 million pounds (Mlbs) of molybdenum in 2012(mining-technology.com, Sep 2013).

Chuquicamate copper mine or Chuqui open pit in Chile, with its 4.3 km length, 3 km width and more than 850 m depth is the second deepest open pit mine in the world (Figure 2.1 Right). The Chiuquicamate coper mine with its more than century operation has produced 443,000t of copper in 2011 for its owner, Chilean state enterprise Codelco(mining-technology.com, Sep 2013)

Figure 2.1 Left: Bingham Canyon mine in US
Right: Chuquicamata Copper Mine in Chile

Source: (Mining-technology.com, 2013).

A particular region of South Africa, owns eight of the ten deepest underground mines in the world and Canada owns the remaining two (Mining-technology.com, 2013). the Mining-technology.com (September 2013) states Mponeng gold mine in South Africa as the deepest underground mine in the world, presently. It has an operational depth between 2.4 km to more than 3.9 km below the surface by the end of 2012. As of December 2012 there was a 13.7 million ounces ore reserve at Mponeng. In 2012 it produces 405,000 oz of gold and presently it is being expanding to extend mine life beyond 2040 (mining-technology.com, Sep 2013).

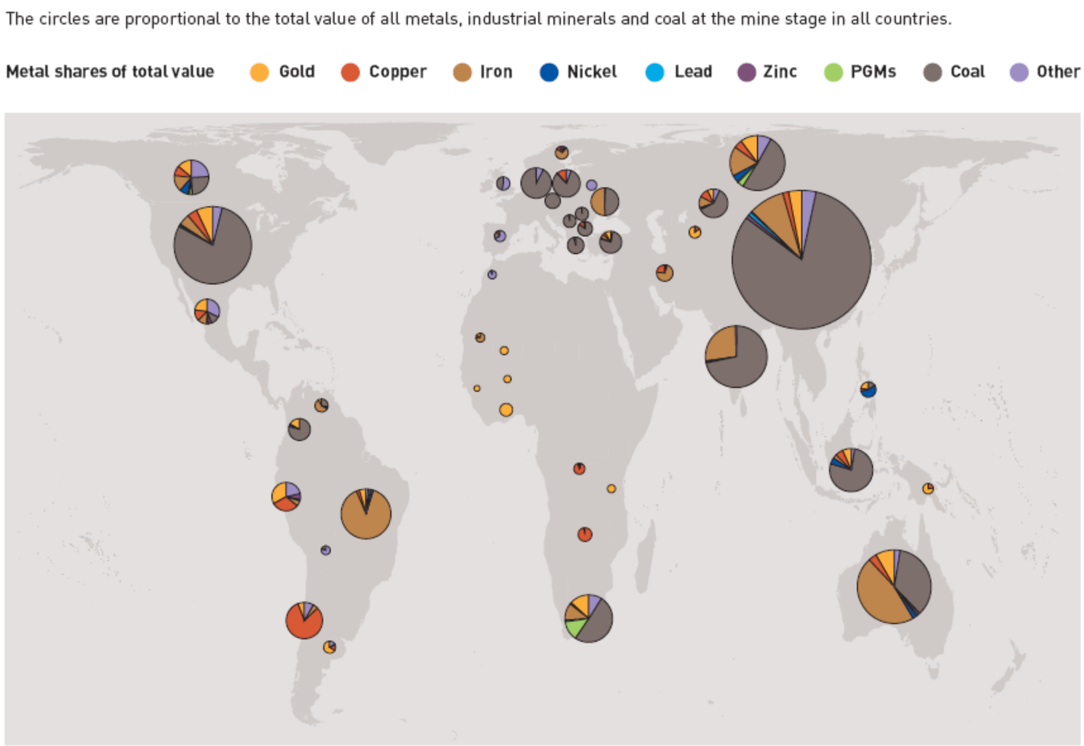

Figure 2.2: Global Mining Activities in 2011

Source: Raw Materials Group, Stockholm, Sweden cited International Council on Mining and Metals (ICMM), 2012

2.1.2 Sri Lankan Mining Industry

Sri Lanka is reasonably endowed with industrial minerals but not with metallic and energy minerals. However, the presence of hydrocarbons within an offshore exploration tenement in Mannar basin has been reported recently and the detailed exploration is in progress (Geological Survey and Mines Bureau (GSMB), 2012). The major minerals resources in Sri Lanka include graphite, mineral sands (ilmenite, rutile, zircon), feldspar, brick and tile clay, ball clay, kaolin, apatite (rock phosphate), silica sand, quartz, mica, miocene limestone, calcite, dolomite, dimension stone, crushed and broken rock, gemstone, seashells (Herath, 2003); (Refer Figure2.3). Industrial minerals such as graphite, mica, mineral sands and quartz are mainly export-oriented mineral commodities in Sri Lanka. All industrial minerals except graphite are mined in quarries or surficial pits by open-cast method. The only two underground working mines for graphite are located at Bogala and Dodangaslanda (GSMB, 2012).

Except for the mines operated by the public sector companies such as Eppawala Apatite Mine, Mineral Sands Mines at Pulmoddai and Kahatagaha Graphite Mine, the other mines are mainly owned by private sector (GSMB, 2012).

Consequent to the expansion of mineral based industries during the past few decades, there is a substantial growth in exploitation of minerals in Sri Lanka (GSMB, 2012).

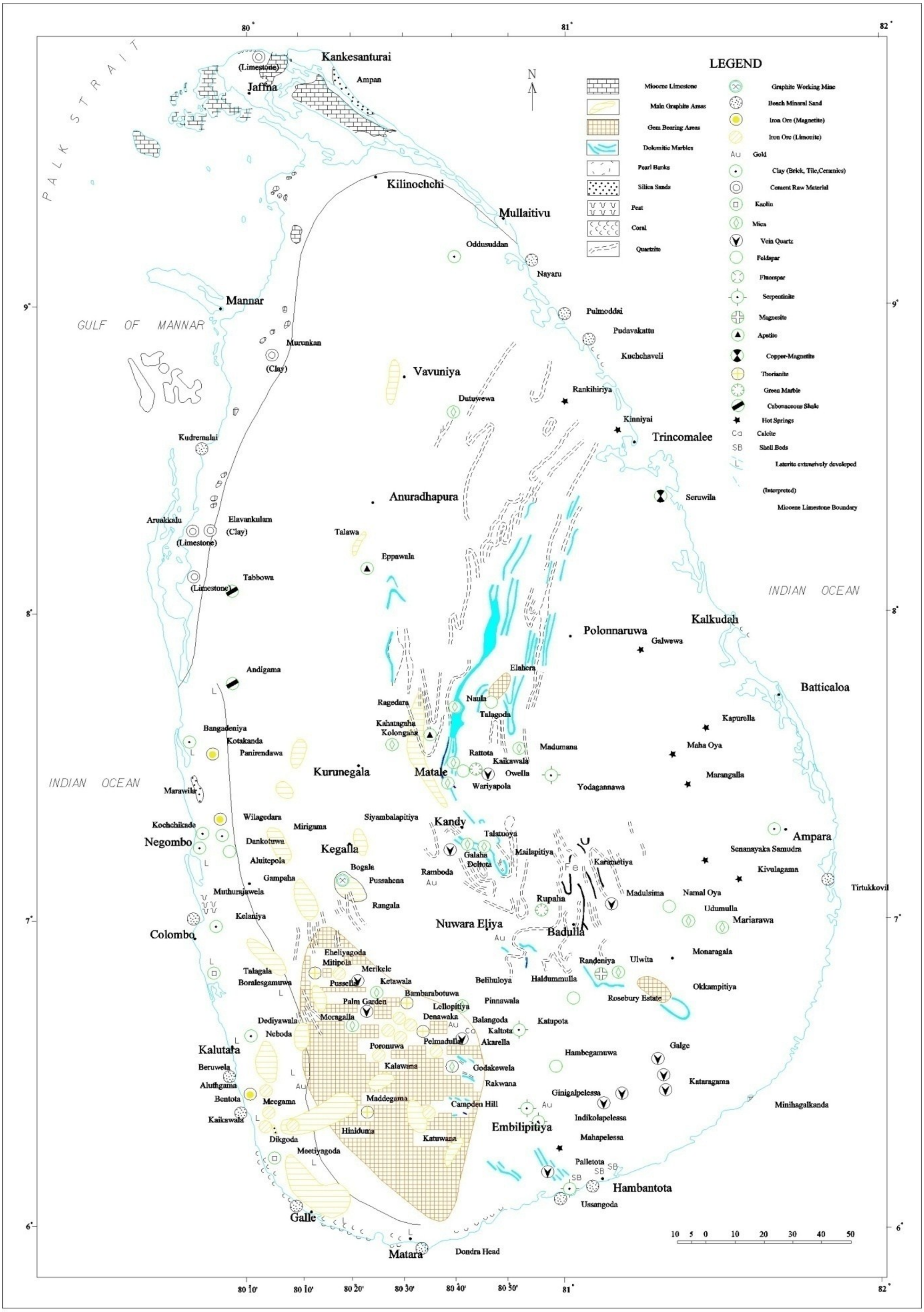

Figure 2.3: Mineral Resource Map of Sri Lanka

Source: GSMB, 2012

2.1.3 Underground and Open Cast Mining

Mining can be divided into two basic type called underground mining and opencast/ surface mining (International Society of Explosive Engineers (ISEE), 1999).

2.1.3.1 Underground Mining

Some mineral deposits are exists very far from the earth surface making it very difficult to access from the surface. Those can only be reached through underground workings (ISEE. 1999).

There are various underground mining methods like chamber and pillar, long-wall, under-level caving, under-level stopping and filling and shrinkage. Choice of the alternative depends roughly on the characteristics of the ore or the geometry of the deposit: dip of the layers or veins, thickness, continuity of the mineralization, grade of ore (disseminated or massive). Levels with a 60m vertical spacing and then sublevels at 15m intervals are the generally opened workings. Two most important criteria for these workings are selectivity of the ore and its percentage recovery (BRGM, 2001).

Series of passages connect all the operations in the ore to one another and to the surface. These passages are opened to the overburden surrounding the deposit. In these passages shafts, inclines, drifts, chutes and cross-cuts are designed for personal and machine access, for removal of ore and drainage water, and for ventilation (BRGM, 2001).

This organization of the operations has the following consequences:

- The ore extraction capacities are generally much lower than for surface mining;
- The quality of waste produced per unit of ore mined is much lower than for surface mining;
- The ground area of this type of underground mine is considerably smaller than for surface mining, except for sub horizontal layers;

- The mechanical risks are different (subsurface collapse, structural weakness around shafts and other inclines).

(BRGM, 2001)

2.1.3.2 Open Cast / Surface Mining

Open cast mining also known as open –cut mining or open –pit mining is a surface mining technique. Here rock or minerals are removed from an open pit or borrow using this surface mining technique (10mostToday.com). From open cast mining methods can extract minerals which are close to the earth surface (International Society of Explosive Engineers (ISEE), 1999). This method is cheap and is used to mine most of the industrial materials and shallow metallic deposits (< 300m). An economic threshold decides the scale of the project, specially the depth and if the threshold limit is being exceeded continuing mining through underground workings would be much better (BRGM, 2001).

Quarries are also one of the surface mining categories. In a quarry, all of the material of a usable size is consumed as an end product. But in other open cast mines end product, which is a desired mineral is mixed with other waste materials. Therefore a subsequent beneficiation operation had to be used to separate these waste materials and deposit them in a convenient, economical and environmentally acceptable manner (ISEE, 1999).

Before the commencement of mining activities soil overburden cover of the mine is removed. Then actual mining is done in successive steps or benches, giving the mine a rough conical shape (BRGM, 2001). Depending on the topography, a mine will be developed as either a side or pit type operation. Where the area is hilly and the rock outcrops, the mine is developed by opening a free face into the side of the hill with bench system (ISEE, 1999).

If the terrain is flat it is important to ramp downward into the deposit, such that the pit created is totally below the surface of the surrounding terrain. The blasting programme is decided by many factors such as geology of the material to be broken, the fragmentation required, the blast hole diameter and depth, and the type of explosive (ISEE, 1999).

In addition to above main two mining types several mining and blasting techniques are used in the construction field i.e. Tunneling, Road way control blasting, Trench blasting, Submarine/ underwater blasting (ISEE, 1999).

2.1.4 Industrial Quarry Project

Quarry operation is similar to heart of the construction industry. All sorts of global road and building constructions needs different types of aggregate, gravel and asphalt for their operation, and this need is satisfied by quarries. Principally the quarry production and consumption is “local” due to its global wide existence (Rylander, 2013).

A broad definition for the quarry is “the depression left on the earth’s surface from which construction aggregates have been taken out”. However in this project, the term quarry implies an open or surface quarry, where “minerals lie near the surface typically where drilling and blasting are required” (ibid cited Kazanovicz, 2013).

Broken or crushed stone (metal/aggregates) is obtained by quarrying from open pit or hillside excavations in the rock outcrops of an area (Herath, 2010). These are one of the most commonly available mineral resources in anywhere of the country and a basic raw material used by the construction industry (Figure 2.4). Different sizes of broken and crushed rocks are produced according to the requirements of building and construction industries (GSMB, 2012). According to the GSMB records, estimation based on the allowable monthly production limits for each category of licences, the total annual production of crushed and broken rock is about 9.8 million cubic meters in Sri Lanka.

According to the Mines and Minerals Act No.33 of 1992, there are main two categories of mining licences. Those are Artisanal Mining Licence (AML) and Industrial Mining Licence (IML). AML is again divided into two categories as AML-A and AML-B. Also IML is divided into three categories i.e. IML-A, IML-B and IML-C. AML is based on the traditional mining method and for the metal quarries this is been operating in a very limited number of quarries. According to the GSMB records, total number of licenced metal quarries in operation is 2,209 up to end of 2011. About 95% of theses quarries are industrial types and only 5% is artisanal type. Further to the GSMB records over the years the numbers of AML quarries have been decreased and the IML quarries have been increased remarkably. Numbers of total metal quarries are also increased from 1709 to 2209 from year 2009 to 2011.

Quarry operation consists with a set of processes (Figure 2.5) and they are same for all quarries(Rylander,2013) and discuss in below.

Figure 2.4: Picture of Quarry Site

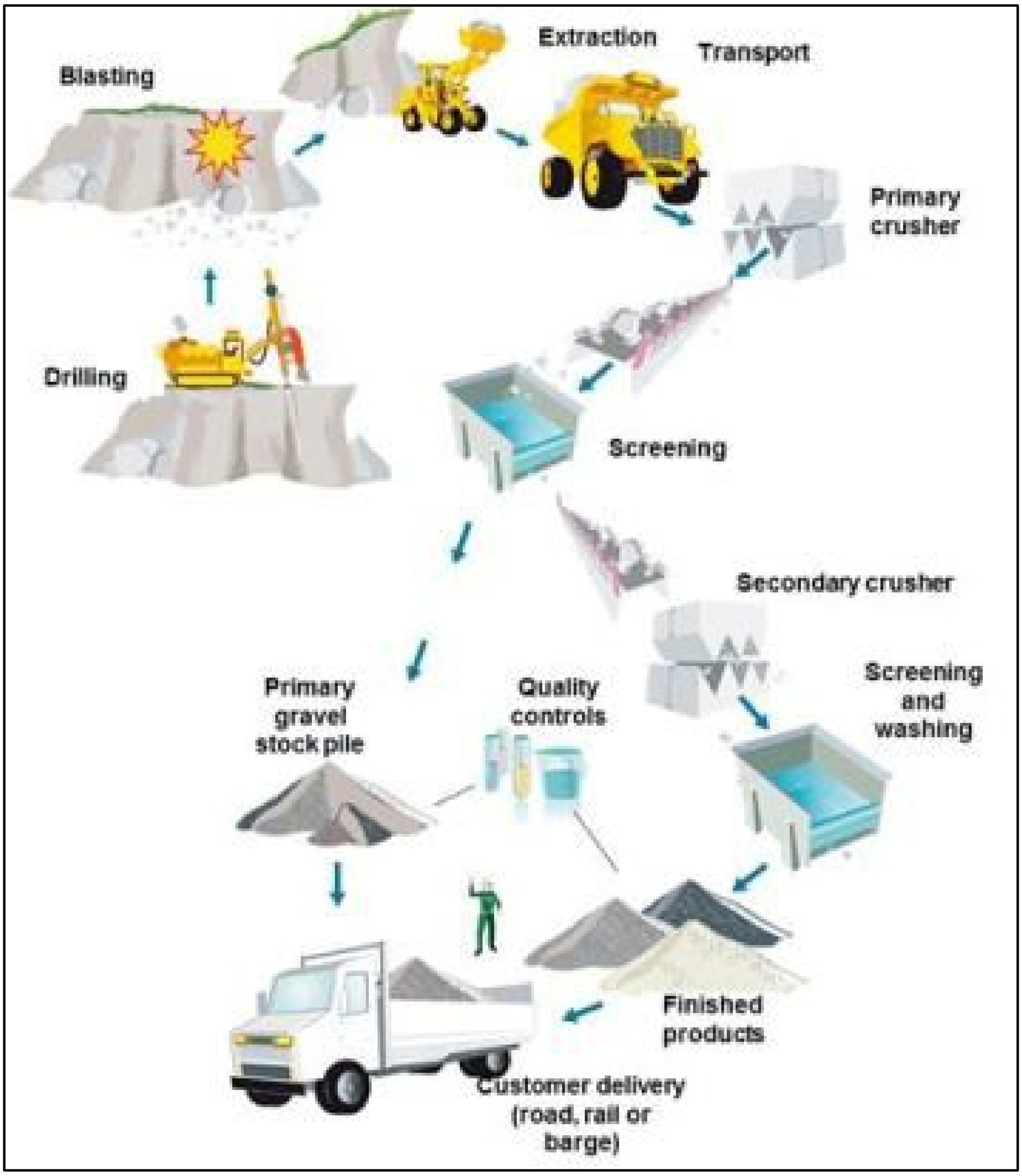

Figure 2.5: Process in Quarry Operation

2.1.5 Process in Quarry Industry

2.1.5.1 Drilling

The first operation in the field of blasting is rock drilling with the intention of opening holes with the adequate geometry and distribution within the rock masses. Explosive charges with their initiating devices will be placed within these holes (Jimeno et al, 1995). A pre-planned drilling pattern describes the suitable spacing, burden, hole depth, hole diameter and number of holes is needed and the drilling is carried out according to this. Among the many types of drilling patterns used for open cat mining, most frequently used are square, rectangular and staggered patterns (ISEE, 1999).

Manual drilling and mechanized drilling are the two types of drilling procedures used in quarry operations. Manual drilling, as its name suggests is the type of drilling done by drillers using light equipment, i.e. pneumatic hand drill machines (Figure 2.6 left). This used when it is difficult to use large machinery due its size or use of large machinery is not economical (Jimeno et al, 1995).

In the Mechanized drilling, drilling equipment is mounted upon rigs with which the operator can control all drilling parameters from a comfortable position (Jimeno et al, 1995). Track drill / crawler drill machines (Figure 2.6 Right) are used in the mechanized drilling (ISEE, 1999).

Figure 2.6 Left: Manual Drilling Using Pneumatic Hand Drill Machine
Right: Mechanized Drilling Using Track Drill Machine

2.1.5.2 Blasting

Quarry will be developed by operating multi bore–hole blasting with open cast bench blasting method. Blasting activities will be carried out in more than one blasting faces and the blasting face will be developed according to bench system in order to avoid unsuitable working conditions (GSMB Technical Services (Pvt) Ltd (GSMB TS), 2012).

Blasting is done using an electrical initiation system of 0-20 or 0-9 delay detonators, in the field of IML A category quarries in Sri Lanka (GSMB TS, 2012). The main explosives use; ANFO (Ammonium-Nitrate with Fuel Oil) as main blasting agent and Dynamite/Water gel/ Emulsion as primer (Jimeno et al., 1995)

There are some steps in the blasting process i.e. charging, stemming, wiring and firing (ISEE, 1999). Explosive charging is normally done manually (Figure 2.8) according to the initially design charging and delay pattern with required quantity of explosives for the explosive column by remaining required height for the stemming (Jimeno et al, 1995). Stemming is also done manually and stemming material will always be of particle size of about 1/10 to 1/20 of diameter of the blast hole and angular crushed stones are commonly used as stemming materials (Blasting and Explosives Quick Reference Guide (BEQRG), 2010) (Figure 2.9 Left). Then the circuit is connected using the series method (Figure 2.9 Right) and checked with an ohm meter before the firing to ensure that each hole has been connected properly and there are no loose connections. Finally the blast is fired with the use of an exploder (Jimeno et al, 1995). All relevant safety precautions should strictly be followed before and after the rock blasting (GSMB TS, 2012).

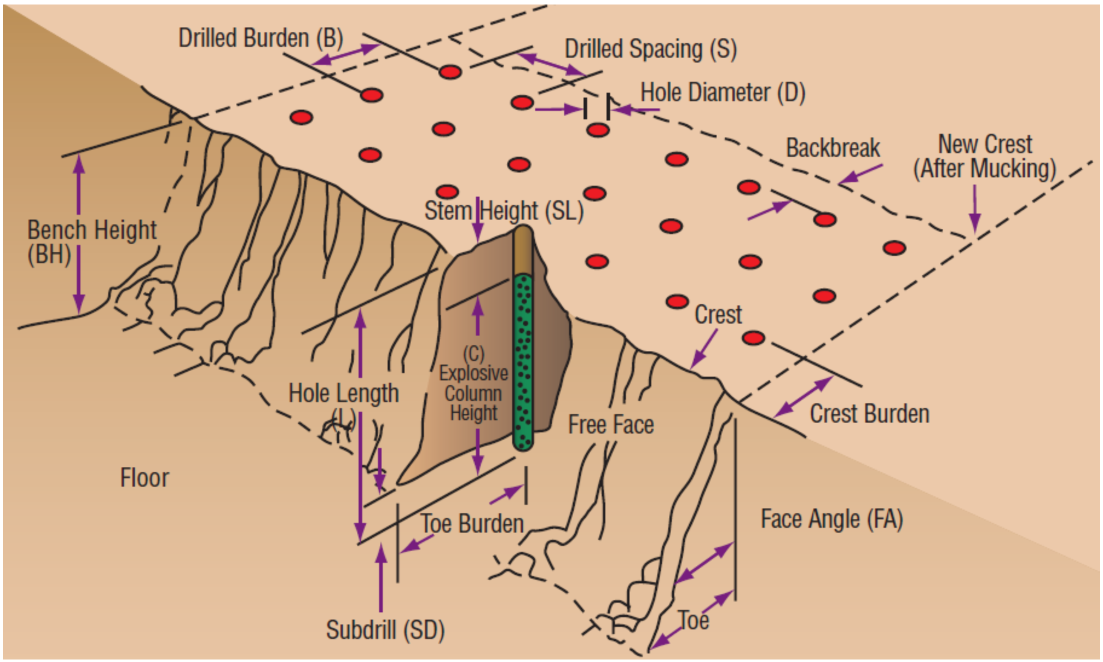

Figure 2.7: Blast Design Terminology

(Source: Blasting and Explosives Quick Reference Guide, 2010.)

Figure 2.8 Left: Charging of Dynamite with ED (Primer)

Right: Filling of ANFO (Main Blasting Agent)

 

Figure 2.9 Left: Doing Stemming Right: Making of Circuits (Wiring)

2.1.5.3 Mucking and Scaling

The blasting will be designed to blast rock through out of bench by blast itself. If some rock left behind on the bench after blasting, it will be mucked out using excavators. Scaling or removing unstable rock pieces hanging from the wall will also be done simultaneously by an excavator or manual labour as required. The blasted rock fallen down to quarry floor will be sorted out to larger boulders and ready to crush blasted rock by an excavator is also included to the mucking process (GSMB TS, 2012).

Figure 2.10: Mucking Using an Excavator

2.1.5.4 Breaking

The sorted out boulders which are larger than the maximum feed size of crushing plant will be broken down by using hydraulic rock breaker attached to an excavator (GSMB TS, 2012).

Figure 2.11: Rock Breaking

2.1.5.5 Loading and Transporting

Blasted rock from the quarry is then loaded into dump trucks by using excavators in order to transport it to feed the crushing plant or directly to customers as necessary. An adequate fleet of dump trucks will be used for this purpose to ensure a continuous supply of rock (GSMB TS, 2012).

Also from the crushing plant, crusher production is loaded by front end loaders to the dump truck and transport to the construction sites (Kazanovicz, 2013).

Figure 2.12 Left: Loading to Dump Trucks
Right: Material Transportation to Processing or Direct Customers

2.1.5.6 Processing/ Crushing

The rocks extracted from the quarry are transported to the processing plants that are generally in the site of extraction (rockydalequarries.com). In the processing plant rocks are fed into crushing machines. The crushing process can be a multi stage process which uses primary and secondary crushes that breaks and fragment mined or quarried rock into various pre-determined sizes (Refer Figure 2.13). Depending on the intended use of the aggregate, primary crushers may be the only equipment employed. If a smaller, more uniform-sized aggregate is required, then secondary and tertiary crushers are utilized (Kazanovicz, 2013).

Crushed stones are separated by size from the screening process. Different screening decks corresponding to each crushing stage are used depending on the line of crushers (Primary, secondary, tertiary) (Dusseaut & Franklin, 1991 cited Kazanovicz, 2013). Finally the finished products are store separately by the size in stockpiles until to be sold or utilized (rockydalequarries.com).

Crusher plant in Sri Lanka basically consists of a feed hopper, a grizzly vibrating federate, a jaw crusher, a cone crusher /an impact crusher, a number of belt conveyors and one / two numbers of three deck vibrating screen unit in order to simultaneously produce different size of aggregates required for road development works and construction industry (GSMB TS, 2012). Complete crusher plant flow chart is as follows (Figure 2.14);

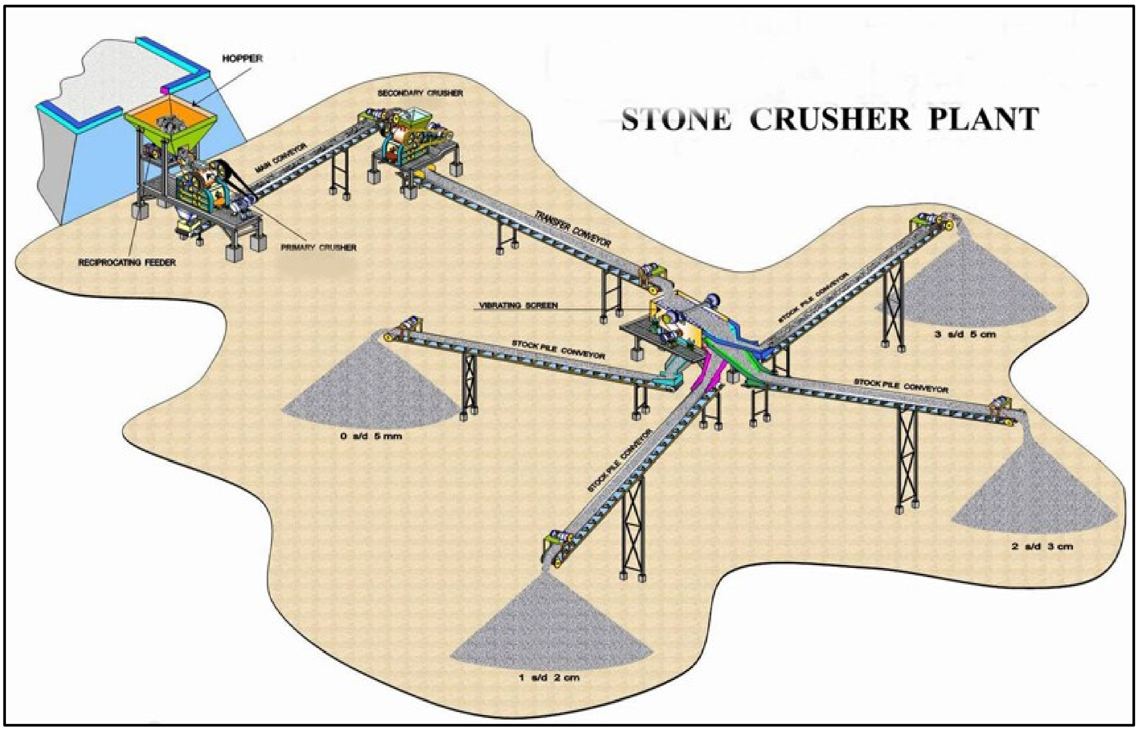

Figure 2.13: Crusher Plant Diagram

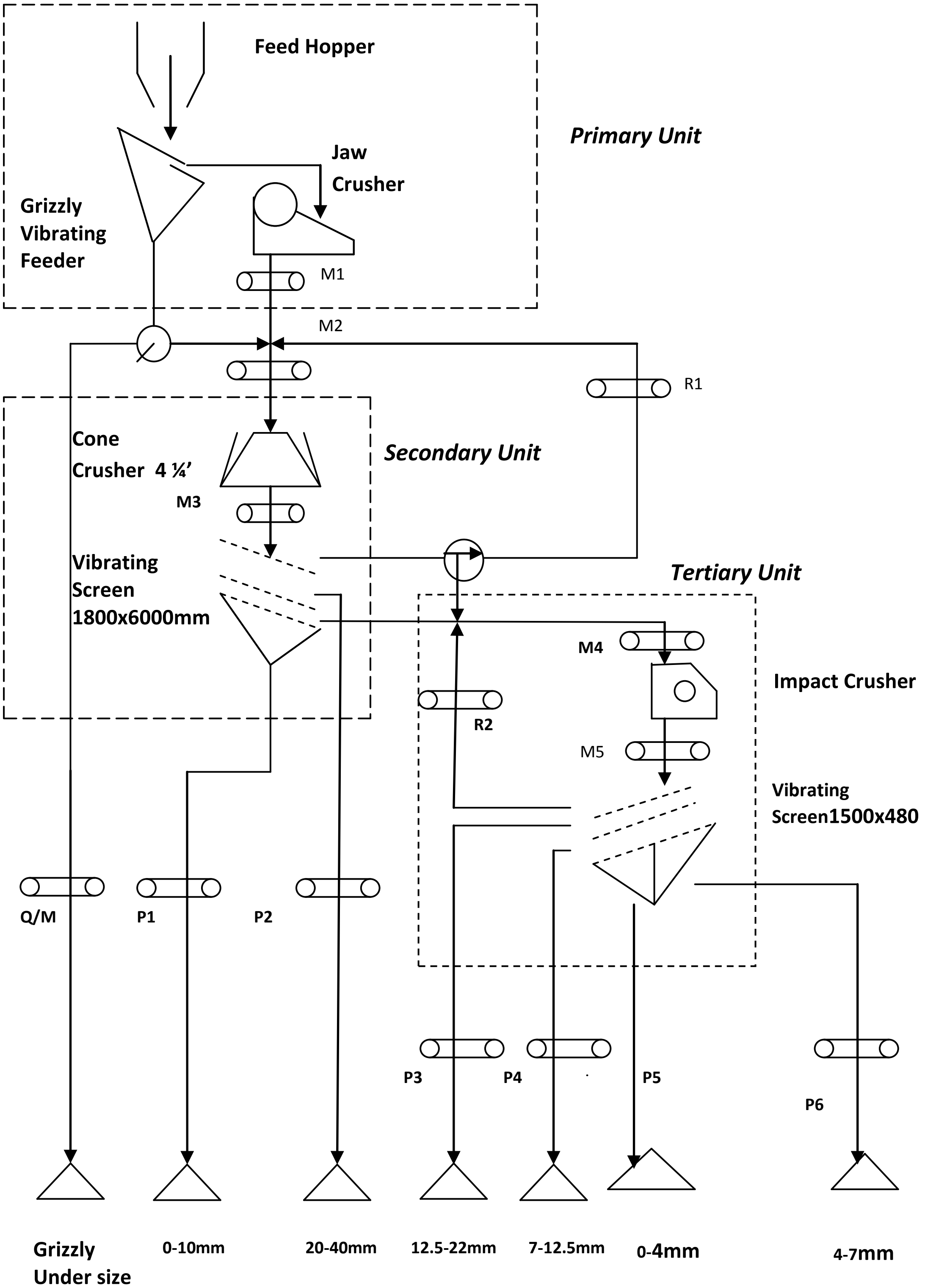

Figure 2.14: Commonly use Crusher Plant Flow Sheet

Source: GSMB TS, 2012

2.2 Lean Philosophy

"Lean" is discussed in many ways such as "Lean Production", "Lean Manufacturing", "Lean Management", "Lean Enterprise", "Toyota Production system" (Drew et al., 2004 cited Mwacharo,2013; Kilpatrick, 2003; Nave, 2002), and "Lean thinking"(Womack & Jones, 2003). It includes a powerful set of tools and techniques that any company choose to execute and sustain as a way of increasing the efficiency of production and the overall customer value by eliminating waste (Drew et al., 2004 cited Mwacharo, 2013).

Lean philosophy is difficult to define yet it has no direct explanation (Petterson, 2009 cited Danansuriya, 2011) and therefore in the literature, there are many definitions available (Marvel &Standridge, 2009). The general opinion of lean is eliminated or reduced all type of waste (Kilpatrick, 2003; Shah & Ward, 2007; Shingo, 1992 cited Senarathne et al., 2009). "Lean" has been originally defined as the elimination of muda (waste) in the book "The Machine that Changed the World" by Womack, Jones, and Roos (Womack et al. 1990 cited Lian & Landeghem, 2002). Womack & Jones (2003) further stated that lean is "half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a product in half the time. It requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products".

Maria (2011) defines Lean Management as understanding customer, reducing waste and optimizing the performances of process, people and infrastructure. Further, lean is, "Adding value by eliminating waste, being responsive to change, focusing on quality, and enhancing the effectiveness of work force" (Liker, 2004 cited Khalil et al., 2013). Another definition for lean is "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability" (Shah and Ward, 2007 cited Marvel & Standridge, 2009).

Singh's (1999 cited Khalil et al., 2013) viewed lean as "A philosophy, based on Toyota Production System, and other Japanese management practices that strives to shorten the time line between the customer order and the shipment of the final product, by consistent elimination of waste". Olivet (2009) sees lean as a global organizational approach with some specific tools in which all available resources are focused on the real value supplied to the customer. This approach identifies all waste along the product or service life cycle. Identified wastes are categorized as mandatory and discretionary where mandatory waste to be reduced as much as possible and discretionary wastes are eliminated immediately. Koskela (1993 cited Senarathne et al., 2009) expresses lean as minimizing or eliminating activities like inspection, waiting and moving that do not add any value to the product or service.

If an organization adopts lean philosophy it can achieve several benefits (Senarathne et al., 2009).Toyoda, (Unknown), states those benefits as fallows;

- Able to supply trouble free products to both internal and external customers.
- Trouble-free products eliminate rework and scrap resulting reducing of production cost
- Reduced cost helps to be competitive in market and increase market share (refer Figure 2.15)

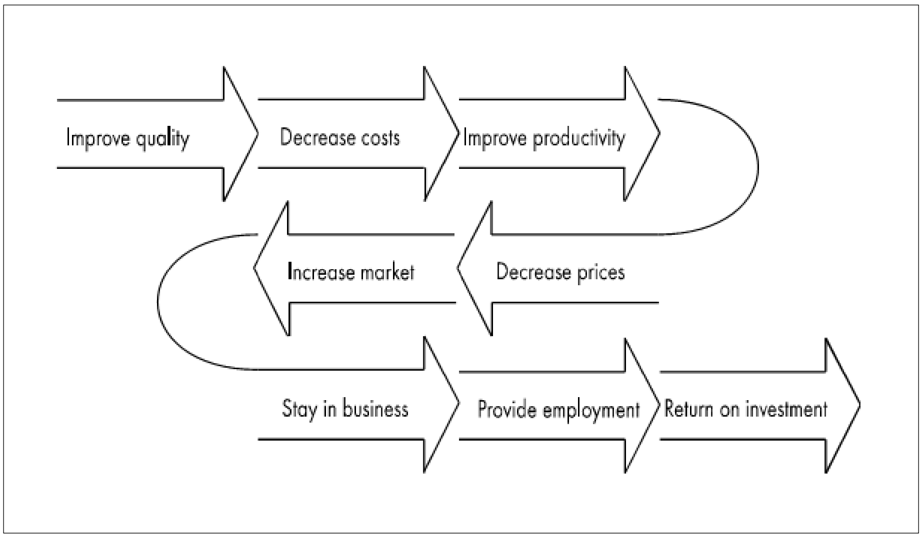

Figure 2.15: The Deming Chain Illustrating how Quality Improvements Reach the Bottom Line.

Source: Toyoda (Unknown)

Further, benefits of applying lean principles to any production process are as follows (Mohan and Iyer, 2005 cited Senarathne et al., 2009);

- Improved productivity
- Reduced wastage
- Reduced working space requirements
- Reduced human efforts
- More sustainability
- Lesser production time
- Increased quality and safety
- Shorter lead time

These benefits help to rapidly penetrate lean principles in to other sectors such as aerospace, electronics, sporting goods, manufacturing, and service sectors such as health care and banking started from automotive sector (USA Environmental Protection Agency (USAEPA), 2003).

2.2.1 History of Lean Philosophy

Henry Ford outlines his production philosophy and the basic principles underlying the revolutionary Ford Production System (FPS) in "Today and Tomorrow" in 1927. After established Toyoda (later Toyota) motor company in 1937 in Japan, Kiichiro Toyoda and Eiji Toyoda with Taiichi Ohno study FPS and developed Toyota Production System (TPS) between 1945 and 1970, and Ohno published TPS in 1978 (Liker, 2004 cited Khalil et al., 2013; Shah & Ward, 2007). Key component of TPS is Just in Time (JIT) production method and the primary goal is cost reduction by eliminating waste. TPS recommends producing only the required units at the required time in required quantity (Shingo, 1989).

Since TPS is versatile and complicated, US managers find it difficult to understand the true nature of the production process. But when US managers captured the fundamentals of TPS and further lean production, these different terms had become very familiar in the academic and business publications (Shah & Ward, 2007).

The term "lean" is firstly used in 1988 by John Krafcik to describe Toyota manufacturing system (Marvel & Standridge, 2009; Shah & Ward, 2007). In 1990 the book titled "The machine that changed the world" was published by Womack, Jones and Roos. The book describes Toyota production system and its underlying components using "lean production". It further describes a lean system in detail, but does not present a precise definition. Then "Lean Thinking" by Womack and Jones was published in 1994 and it extends the philosophy and the guiding principles underlying lean to an enterprise level (Womack & Jones, 2003). Currently, there are many academic and expert books and articles defining lean production (Shah & Ward, 2007).

2.2.2 Lean Principles

2.2.2.1 Womack and Jones's Principles

Womack and Jones (2003) summarized lean in to five principles;

1. Specify value
2. Identify the value stream
3. Flow
4. Pull
5. Perfection

1. Specific value

Internal and external customer standpoints determine which features create value in the product. Value is expressed in terms of how the specific product meets the customer's needs, at a specific price, at a specific time. Specific products or services are evaluated on which features add value. The value determination can be form the perspective of the ultimate customer or a subsequent process (Womack & Jones, 2003, p.16).

2. Identify the value stream

The total process through which a specific product or service is achieved can be express as the value stream. This value stream consists of three critical management tasks as follows (Womack & Jones, 2003, p.19) and shown in Figure 2.16.

- Problem solving task: This involves creating a product from a concept through design and engineering.
- Information management task: Order-taking through detailed scheduling to delivery.
- Physical transformation task: Transformation of raw materials to a finished product.

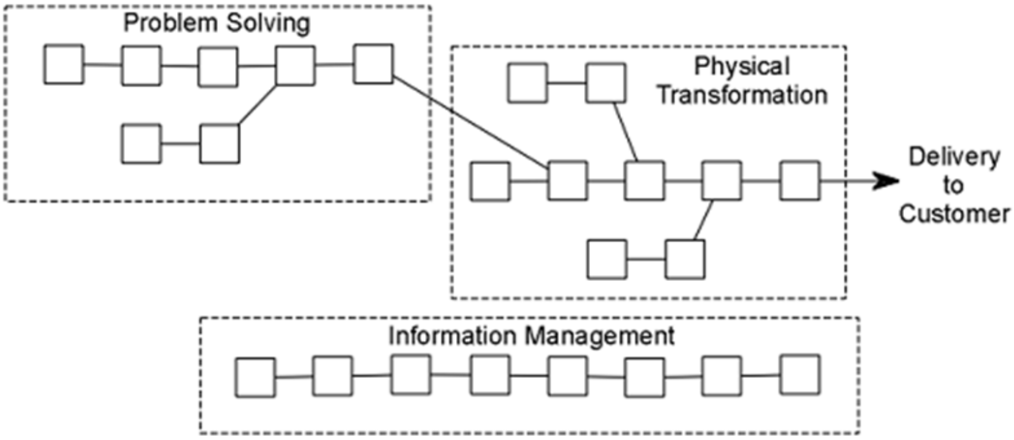

Figure 2.16: The Lean Production Value Stream

(Source: Dettmer, 2008)

When analyze a value stream can identify three types of actions (Womack & Jones, 2003, p.20):

1. Many steps contribute directly or indirectly to creating the product characteristics important to the eventual customer.
2. Many other steps although with no value are unavoidable due to current technologies and production assets. (Type one waste/ muda)
3. There can be found many steps with no value and are avoidable. (Type two wastes/ muda)

3. Flow

Flow is the third principle. After the identification of value adding activities and necessary non-value adding activities, improvement efforts are directed to make the activities flow. Flow is identified as the movement of product or services through the system to the customer, uninterruptedly. In order to make work valued by the customer move through the system rapidly and smoothly, such as without any starts-and-stops inherent to batch-and-queue operations, work functions, departments, and firms are redefined by the lean alternative (Womack & Jones, 2003).

4. Pull

Short-term response to the customer's rate of demand without any overproduction is defined as Pull. In other words Pull is make-to-order. Remarkable savings in both work-in-process and finished inventories can be realized by an effective Pull system. Nevertheless only an exceptionally fast, smooth flow is needed for the success of the Pull philosophy (Womack & Jones, 2003, p.24).

5. Perfection

Perfection is the last principle. By repeating first four principles in a continuous, ever-tightening cycle (Figure 2.17), perfection concept implies the never ending process of reducing effort, time space, cost, and mistakes while offering the customer with the best of product that suits customer needs perfectly (Womack & Jones, 2003, p.25). "Getting value to flow faster always exposes hidden muda in the value stream. The harder you pull, the more the impediments to flow are revealed so they can be removed" (Womack & Jones, 2003, p.25).

Figure 2.17: Continues Cycle of Five Lean Principles

Source: http://www.lean.org/WhatsLean/Principles.cfm

2.2.2.2 Koskela’s Lean Principles

Koskela (1992) developed eleven sub principles under a core principle moving towards the lean production that applies to construction industry (Senarathne et al., 2009). Core principle is based on the conversion activates and flow activates. Those are:

I. Conversion activities – These are value adding activities or piece of information transformed in to a product and corresponded by processing (Koskela, 1992 cited Senarathne et al., 2009).

II. Flow activities – These are non- value adding activities which bound conversion activities together and corresponded to inspection, moving and waiting (Koskela, 1992 cited Senarathne et al., 2009).

As for Koskela (1992) a core principle is supported by eleven sub principles, so that these sub principles helps to design, control and improve flow process of the production (Figure 2.18).

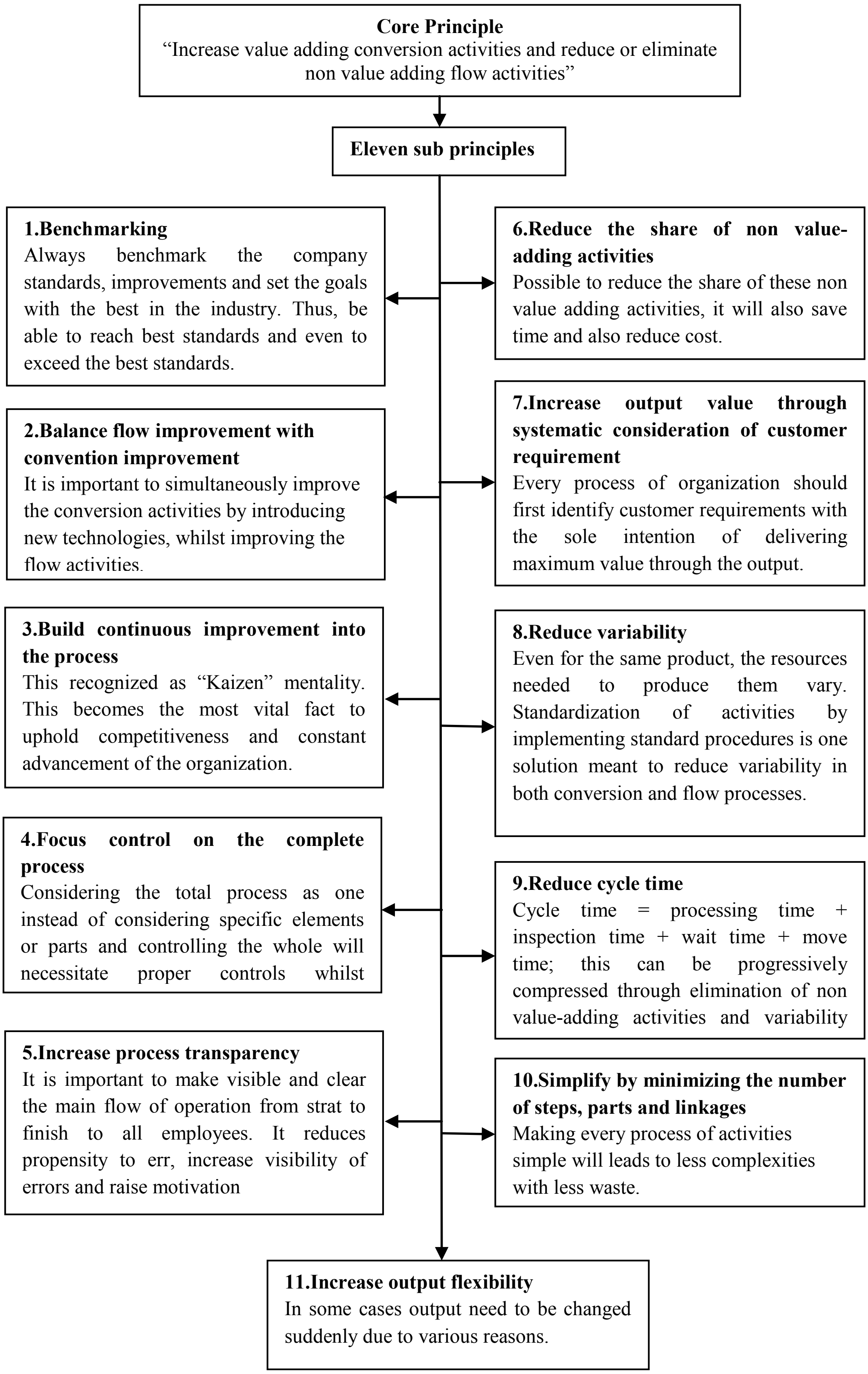

Figure 2.18: Lean production – Eleven Sub Principles

Source: Koskela, 1992

2.2.2.3 Henderson and Larco's Lean Principles

Henderson and Larco (1999 cited Goforth, 2007 cited Weerasingha, 2009) describe lean production principles in another way as shown in Figure 2.19.

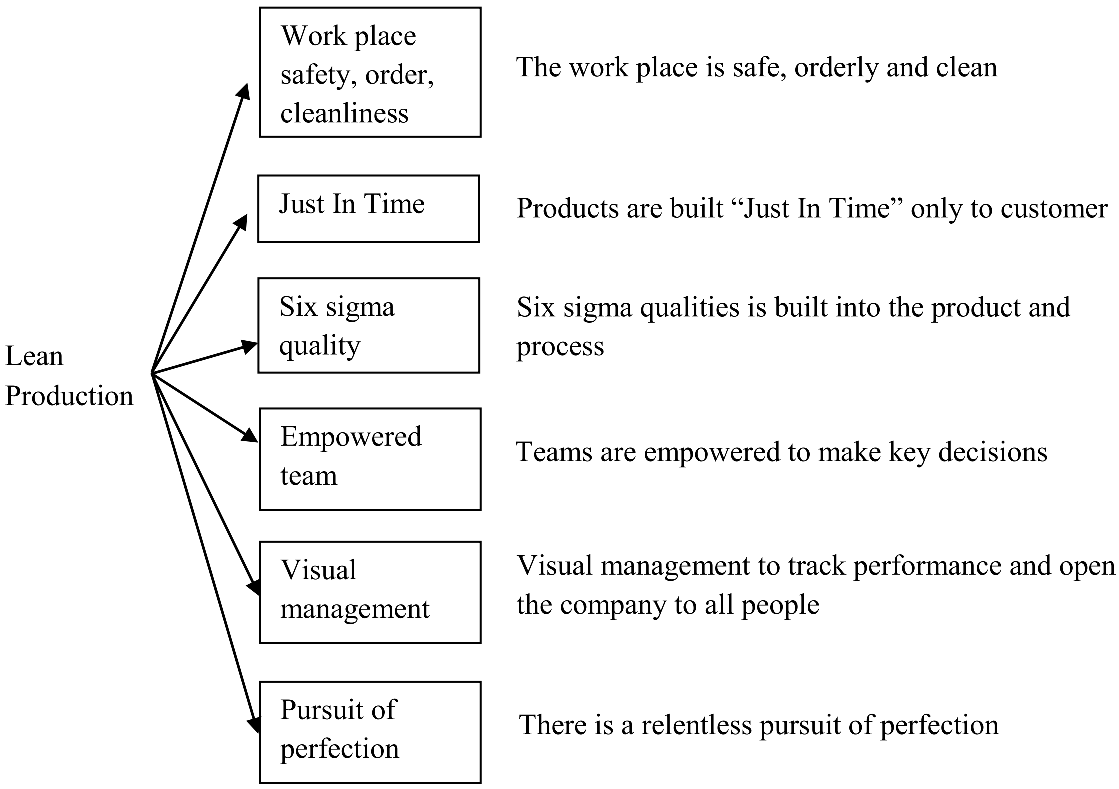

Figure 2.19: The Lean Production Principles

Source: Henderson and Larco, 1999 cited Goforth, 2007 cited Weerasigha, 2010

2.2.2.4 Chinh and Nhon's Principles

According to Chinh and Nhon (2007 cited Weerasigha, 2010) main principles of lean are awareness of waste, standerdized work, continuous flow, pull production (Just in Time), quality at the source and continues improvement.

However this dissertation is based on initially explained five lean principles of Womak and Jones.

2.2.3 Types of Wastes

Lean principles are mainly focus on wastes (Kilpatrick, 2003). Any activity in a process which does not add value to the customer is called as waste (Melton, 2005). The wastes are also commonly referred to as Non Value Added Activities (NVAA) (Kilpatrick, 2003).

TaiichiOhno (1912 – 1990), the Toyota executive identified first seven types of muda i.e. overproduction, waiting, unnecessary transportation, over processing, inventory, unnecessary movements, defects (Womack & Jones, 2003). Muda is a Japanese word for waste (Womack & Jones, 2003). Further, another type of waste has added that is ‘Underutilized People’, and now it is known as 7 + 1 waste (Andi et al., 2009).

Various researchers pointed out waste in different ways in there surveys. However all these wastes fall into above mention eight type of mudas directly or indirectly. Table 2.1 summarizes waste categories mentioned in various literatures.

Table 2.1: Literature Summary on Different Type of Wastes

NVAA/ Wastes		**Literature**												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	Over production	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
2.	Waiting/Delay	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
3.	Unnecessary Transportation	**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	**X**		**X**
4.	Unnecessary Processing	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
5.	Excess Inventories	**X**	**X**	**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	**X**
6.	Unnecessary Movement/Motion	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
7.	Defects	**X**	**X**	**X**	**X**		**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
8.	Underutilized People				**X**	**X**		**X**	**X**				**X**	**X**

(1). Ohno, 1988 cited Womack and Jones, 2003 (2). Toyoda, Unknown (3). Melton, 2005

(4).Fargher, 2014 (5). Productive Development Team, 2000 cited USA Environmental Protection Agency, 2003

(6).Akinlawon, Unknown (7).Larman and Vadde, 2009 (8). Kilpatrick, 2003 (9).Capital, 2004 cited Khalil et al., 2013 (10). Shingo, 1989

(11). Imai, 1997; Shingo, 1984; Walton, 1999 cited Senarathna et al., 2009 (12).Ohno, unknown cited Keiser, 2010

(13).Andi et al., 2009

The above mentioned waste types are explained in Table 2.2.

Table 2.2: Waste types with their descriptions

	Waste Types	**Description**
1	Over production	Produce more than the customer demands, or product made for no specific customer, or producing too early it need to customer. This creates excessive lead time, high storage cost and difficult to detect defects.
2	Waiting/Delay	Any waiting due to machine and / or plant breakdowns and / or maintenance, poor layout, changeovers. Also waiting for materials, information / instruction, equipments and tools. Further it includes delays between subsequent processing steps and increase production cycle time without adding value to the product.
3	Unnecessary Transportation	It includes any movement of materials and people that does not add any value to the product. Therefore material should progress from one position to the next as quickly as possible without stopping at any intermediate storage place and it result is double handling. Also the work teams and support units should be located close together.
4	Unnecessary Processing	This includes processes that take unnecessary time or effort and redundant process steps.
5	Excess Inventories	Storage of raw materials, intermediate and finished products unnecessarily.
6	Unnecessary Movement/Motion	Excessive movement of people or machines that does not add value to the product or service. It includes unnecessary amount of turning, lifting and reaching. Also workers walking to looking for parts, tools and helps.
7	Defects	Product or service which does not meet the customer specifications due to poor internal quality. It requiring re-work or additional work.
8	Underutilized People	Poor work flow, organizational culture, inadequate hiring practices, poor or non- existing training and high employee turnover results underutilization of mental, creative, physical skills and abilities of people.

(Sources: Capital, 2004 cited Khalil et al.,2013; Kilpatrick, 2003; Melton, 2005; Fargher, 2014; 2013; Productive Development Team, 2000 cited USA Environmental Protection Agency, 2003; Toyoda, Unknown)

2.2.4 Lean Strategies

The most common lean strategies/ tools that applied in lean management are highlighted below.

2.2.4.1 5S Concept

This strategy can easily be implemented and can turn messy disorganized work place in to an organized, systematic one. As a result employee mentality will develop and would change from a negative thinking mind set in to a positive thinking mind set (Bicheno & Holweg 2009 cited Mwacharo, 2013).

Below is a simple illustration of 5S (Table 2.3).

Table 2.3: Simple illustration of 5s

Original Japanese version	**English meaning**	**Illustration**
Seiri	Sort	Separate unnecessary materials from necessary ones and remove those.
Seiton	Set in order	Organize remaining materials so that they can be easily identified.
Seiso	Shine	Clean and inspect work place
Seiketsu	Standardize	Conduct above 3 periodically to maintain workplace in a perfect condition.
Shitsuke	Sustain	Form a habit to follow 5S

(Source: Womack & Jones, 2003)

2.2.4.2 Just-In-Time (JIT)

This technique describes how to achieve continuous improvement through continuous process of eliminating wastes. Examples for wastes are excess lead times, overproduction, excess inventory and scrap (Huang et al., 1983; Lai, 2009 cited Mwacharo, 2013). Specially, this technique reduces in-process inventory to absolute minimal levels (Huang et al., 1983).

The main objective of JIT is to "producing and delivering the right items at the right time in the right amounts" (Womack & Jones, 2003). JIT indicates the pull system which means that production is done according to the pull by customer demand instead of producing according to the projected demand (Sugimori et al., 1977).

JIT is a combination of many other lean tools such as Continuous Flow, Heijunkan, Kanban, Standardized Work and Takt Time (Womack & Jones, 2003).

2.2.4.3 Kaizen

Kaizen is one of the most recognized Japanese words. Meaning of 'Kai' is continuous and 'zen' is improvement hence Kaizen simply means continuous improvement (Trent 2008 cited Mwacharo, 2013). Main idea behind Kaizen is identifying regular incremental improvements needed which create more value with less effort. Kaizen is a team effort and employees at all levels should be involved (Womack & Jones, 2003).

Kaizen process consists of three stages; preparing for the Kaizen event, performing the event, and checking whether improvements are truly beneficial and if they are, whether they are permanent. Most kaizen events focus on a company's internal processes, but it is applicable for any part of the supply chain (Trent 2008 cited Mwacharo, 2013).

2.2.4.4 Kanban (Pull System)

Kanban is a method of labeling small production lots in order to attain a tighter control of raw materials, purchased parts, and work-in-progress, as well as of the rate, total volume, and timing of production (Gravel & Prices, 1988).

Aim of Kanban is to eliminate waste from inventory and overproduction by regulating the flow of goods within the factory and with outside suppliers and customers. This uses a signal card system to specify the need of goods (Gravel & Prices, 1988).

A typical manufacturing system uses "push" system in which created materials are pushed through the system without the need. But the traditional Kanban technique inherits “pull” system in which materials are created only when they are taken. There are three main functions for a traditional Kanban system (Shingo, 1989).

- Identification tag – indicates what the production is
- Job instruction tag – indicates what should be made, for how long and in what quantities
- Transfer tag – indicates from/ to where the item should be transported.

In Toyota Production System (TPS) from only two tags above three functions could be fulfilled (Shingo, 1989).

- Work-in-process tag – serves as identification and job instruction tags
- Withdrawal tag - serves as identification and transfer tags

2.2.4.5 Value Stream Mapping

Value Stream Mapping (VSM) is the visual mapping tool used to identify and eliminate waste. That shows the current and future state of processes in a way that highlights opportunities and provides a roadmap for improvement (Rother and Shook, 1999 cited Lian & Landeghem, 2002).

A product’s information and material flow is described by the VSM, therefore, it can be used to identify value adding and non- value adding functions within a company. Before the separation of value adding and non- value adding tasks, linkages between information and material flow and individual tasks within these linkages are documented. Then the future state map is created using the value adding tasks and non value adding tasks are assessed to ensure whether they can be eliminated. (Bicheno and Holweg, 2009; Hobbs, 2011 cited Mwacharo, 2013).

2.2.4.6 Poka-Yoke

Shigeo Shingo in 1961 introduced Poka-Yoke method and it is translated as “resistance to errors” (Burlikowska & Szewieczek, 2009). Therefore Poka-Yoke is a technique for avoiding and eliminating mistakes. It detects and prevents design error into process to achieve zero defects (Kotala& Roberts, 2001 cited Burlikowska & Szewieczek, 2009).

This technique prevents occurring of problems or defects, or stops the process immediately if a problem occurs. A typical common example is the clutch in a car which will not start unless the clutch is pressed (Drew et al., 2004 cited Mwacharo, 2013).

Poka-Yoke has three basic functions to prevent or reduce defects: shutdown, control, and warning (Shimbum, 1998 cited Burlikowska & Szewieczek, 2009).

2.2.4.7 Takt Time

Takt Time is the average rate at which a company must produce a product or execute transactions based on the customer's requirements and available working time (Chandra, 2013).

Decrease of Takt time implies that customers are buying more of a product and vice versa. For an example this information can be used by a company to determine their optimal staff i.e. the correct number of staff to be worked at a specific Takt time, no more or less (isixsigma 2013cited Mwacharo,2013).

Balancing the output of sequential production processes and prevention of inventory buildups and shortages are the primary intentions of Takt time (McManus, 2005).

2.2.4.8 Total Productive Maintenance (TPM)

This technique focuses on proactive and preventive maintenance to maximize the operational time of equipment by establishing a comprehensive productive-maintenance system covering the entire life of the equipment with the participation of all employees. That is equipment are maintained properly and periodically instead of mending it when a break down occurs (Tsuchiya, 1992 cited McKone et al., 2001).

Advantages of TPM are (Kilparick, 2003);

- Eliminating of breakdowns
- Reduction of unscheduled and scheduled downtime
- Improve utilization
- Higher throughput
- Better product quality
- Low operating costs
- Higher equipment life time
- Low overall maintenance cost

2.2.4.9 Continues Flow

Continues flow is the concept of moving product through a value stream at a constant rate throughout the value stream or with minimal (or no) buffers between steps of the process (leanproduction.com, 2010-2013; leantools & techniques, 2007). It helps to eliminates many form of wastes such as inventory, waiting time, and transport (leanproduction.com, 2010-2013).

2.2.4.10 Bottleneck Analysis

In any manufacturing process normally overall throughput is limited by a certain weak link. Bottleneck Analysis identifies this weakest link and improves the throughput by strengthening it (leanproduction.com, 2010-2013).

2.2.4.11 Total Quality Management (TQM)

TQM is an integrated management philosophy which is applicable to all areas of company’s operation and recognizes the strength of employee involvement (Kilpatrick, 2003). This management system emphasizes on continuous improvement, meeting customer requirements, reducing rework, long range thinking, increased employee involvement and teamwork, process redesign, competitive benchmarking, team-based problem solving, constant measurement of results, and closer relationships with suppliers (Ross, 1993). Since TQM mainly focuses on preventing of occurring errors, it helps to improve the quality (Black & Porter, 1996).

2.2.4.12 Visual Controls / Visual Management

Visual Controls are merely efficient, self-regulating, worker managed, simple signals which defines work areas, product flow etc. These are used to get an immediate, instant and clear understanding of a condition or situation. When someone walk into a workplace, with the help of this visual controls he is able to realize particulars about production schedule, backlog, workflow, inventory levels, resource utilization and quality within a very short period of time such as thirty seconds. Visual controls include Kanban cards, lights, colour-coded tools and lines defining work areas and product flow, etc. (Kilpatrick, 2003)

2.2.4.13 Daily Huddle Meeting

This is an employee involved improvement cycle with two-way communication. Everyday team members meet briefly before the commencement of their work (brief daily start-up meeting) to discuss how their work had proceeded since previous day's meeting. Here also tries to identify issues that affect the timely completion of an assignment. (Badurdeen, 2007 cited Danansooriya, 2011)

2.2.4.14 Plan Do Check Act (PDCA)

This is an iterative methodology for implementing improvements;
Plan – Establish plan and expected results
Do – Implementing plan
Check – Verify expected results achieved
Act – Review and assess; do it again (Hervani et al., 2005)

End results standards are continuously improved upon in a cyclic pattern. If something went wrong it is indicated by the large deviation from the standard (Bicheno & Holweg 2009 cited Mwacharo, 2013).

2.2.4.15 Cellular Manufacturing/ Manufacturing Cells

The main feature of this concept is that there is a smooth flow of materials and components through the production process, resulting minimal transport or delay. This is achieved by arranging production work stations and equipment in a product-aligned sequence (US Environmental Protection Agency (USEPA), 2003). Therefore there is an increase in mix of products with minimum waste (Kilpatrick, 2003). This concept helps to increase production velocity and flexibility and reduce capital requirements such as excess inventories, facilities, and large production equipment (USEPA, 2003).

2.2.4.16 Jidoka (Autonomation)

Jidoka is often translated as "autonomation" or "automation with a human mind". This concept suggests to partially automate the manufacturing process and to stop the process automatically when a defect is detected rather than continue to run and produce bad output (Ohno 1988, Monden, 1993 cited Danovaro et al., 2008). Therefore Jidoka has two qualities: a mechanism to detect problems and a mechanism to stop the production line or machine when a problem occurs (Monden, 1993 cited Danovaro et al., 2008). Some authors explain Jidoka as "quality-at-the-source" because of the quality is inbuilt in the production system and it is not necessary to checked after the process (Monden, 1993 cited Danovaroet al., 2008).

2.2.4.17 Work Standardization

Work standardization means advancing to work specifications and instructions in an organized manner. In Toyota, the exact manner of performing each task is specified by work groups, and then they adhere to it. When the group identifies need for improvement, changes are made (Lean tools and techniques, 2007).

Due to this concept, variations resulting from differences in work methods are reduced because all workers execute their work in the same manner (Lean tools and techniques, 2007).

2.2 Waste in Quarry Industry

Anything other than the minimum amount of equipment, materials, parts, space, and worker's time which are absolutely necessary to add value to the product are considered as waste (Arnold, 2011).

In quarry operations if customers' specifications or requirements are not met, then it can be considered as a waste. For example aggregates that do not meet product specifications and late deliveries can be considered as waste(Caldwell).

Also if aggregates are made more than the amount required by next process, it is a waste. Also making it earlier or faster than the requirement does not add any value to the process hence a waste. Rock in the pit can be considered as a good example for this kind of waste (Caldwell).

Unnecessary waiting/delays that occurs in quarry operations are clearly non value adding. For instance waiting for equipment, waiting for parts, tools, supplies, etc., waiting for upstream operations (i.e. drilling, blasting) , waiting for clarification of instructions and waiting on employees to show up are also wastes that are for most of time overlooked (Caldwell).

Also many quarries take greater efforts to add value to their product but in the customers' view point it is useless. Following are some examples for this kind of waste. Tolerances/ specs beyond customer needs, multiple screening, collecting data that no one needs and multiple data entry on separate computer systems (Caldwell).

In quarries transpotation waste occur mainly due to poor work flow. If illustrated further transpotaion waste is transporting rock, work-in-process and finished inventory around the pit(Caldwell).

If finished goods, raw materials and/or spare parts are stored in excess, inventory waste occur. This may result unnecssary space requiremnts for the quarry(Caldwell).

Non value adding movement of people or equipment is also considered as a waste that should be avoided immediately. Walking /driving to the job sites, looking for lost paperwork or work orders and walking to get supplies or raw materials are some ways that motion waste can occur(Caldwell).

If employees' mental, creative and physical abilities are not used properly it is also considered as a waste. Situations where employees are not given proper training or when they are micromanaged are some of the examples for this type of waste(Caldwell). This can lead to employee turn over. And when employees leave, they take valuable process knowledge, customer and supplier relationships and a host of organizational know-how with them which is a waste for the industry (Schultz & Grimm, 2008).

2.3 Application of Lean Concept in Mining Industry

Over the past 30 years, majority of manufacturing industries have applied lean and other industries including mining industry have started to absorb the lean concept (Andi et al., 2009).

There are two major reasons to apply lean concept to the mining industry. They are;

1. Decreasing of profitability
   Due to increasing cost allied with the social and environmental demands of sustainable development (Humphreyes, 2001 cited Andi et al., 2009).
2. Both automotive and mining industries share common view
   - Both rely on effective business processes
   - Both rely on efficiency within the value stream
   - Both attempt to maximize operational efficiency
   - Both rely on an extensive supply chain
   - Both sectors have ruthless focus on safety (Colard et al., 2007 cited Andi et al., 2009).

Klippel, Petter and Antunes (2008), have practically show the benefit of implementing lean to the mining industry by their selected cases of two underground mining projects. Those are fluorspar mine and amethyst mine in Brazil. The study has identified wastes related to basic 7 wastes in lean principle. By minimizing identified wastes they have achieved considerable increase in efficiency and quality of worker's life. In the fluorspar mine, there was a cost reduction from US$ 5.23 to US$ 3.51 inside the mining block and increase the productivity from 32.9% to 43.6%. In the amethyst mine the main improvement was in relation to quality of worker's life by reducing the dust concentration inside the galleries from 60.3 mg/m^3 to 3.2 mg/m^3 and also reducing the waste caused by waiting from 50.87% to 32.09% of the waiting time. Therefore this research is a good example to understand the value of applying lean principle to the mining industry.

Andi, Wijaya, R.Kumar and Kumar (2009) identified the issues and challenges of implementing lean principles into mining industry. According to the findings, lean principle can be successfully applied to the mining industry, but have to consider many issues and manage those in a smart way. Rosienkiewicz (2012) introduced the idea of adaption of Value Stream Mapping (VSM) Method to the mining industry and used that technique to identify the waste. Those researches have only based on underground mining projects, and have not discussed about open cast mining projects.

LMR, originated in United Kingdom is one of the market leaders for lean solutions. They are giving consultancy and services to implement lean to increase productivity and reduce unit cost of sectors i.e. aerospace, automotive, mining, public sector, service sector, manufacturing and healthcare. LMR has successfully applied lean to the large scale open pit and underground mining projects in Australia. In one of the open pit gold mining project, LMR applied lean techniques to reduce the operating cost by removing heavy mobile and additional equipment. After the implementation of lean, the company achieved 20% reduction of mobile fleet along with other savings provided a 14 : 1 return on invest with LMR, and the required reduction in unit cost (http://www.goinglean.co.uk/).

One of the group mining company produce seven type of mineral commodities i.e. copper, coking coal, thermal coal, ferrochrome, nickel, vanadium and zinc wanted to develop a process to maximize the output on a mine with the remaining operating life of three years and they asked LMR to develop it. Operations and the projects of the company cover 18 countries and have over 50,000 employees and contractors. After implementing several lean techniques, company saw a 22% increase in production output (http://www.goinglean.co.uk/).

Rylander (2013) has researched to identify waste in quarry operations by applying lean value stream mapping method. This has been discussed in a very narrow area of the quarry processes and has not given solutions to minimize wastes. The researcher has only given the attention for finding waste in activities which are from transporting to crusher to delivering to customers in quarry operation.

2.4 Conceptual Model of the Research

Eight common Industrial wastes/ none value adding activities i.e. Over production, Waiting/ delay, Unnecessary Transportation, Unnecessary Processing, Excess Inventory, Unnecessary Movement/ Motion, Defects, Underutilized People identified from the literature survey were considered for this study. One objective of this study is to find the factors affecting wastes in Sri Lankan quarry industry under the above mentioned main waste categories. Further it is expected to identify relevant action or strategies to minimize above wastes. The conceptual model developed for this study using the literature review is shown in Figure 2.20.

Left side of this model shows factors affecting wastes in Sri Lankan quarry industry under 08 types of wastes identified through literature review (Refer Table 2.1). The right side of the model shows lean strategies to minimise factors affecting wastes and optimize the performance of quarry industry (Refer section 2.2.4)

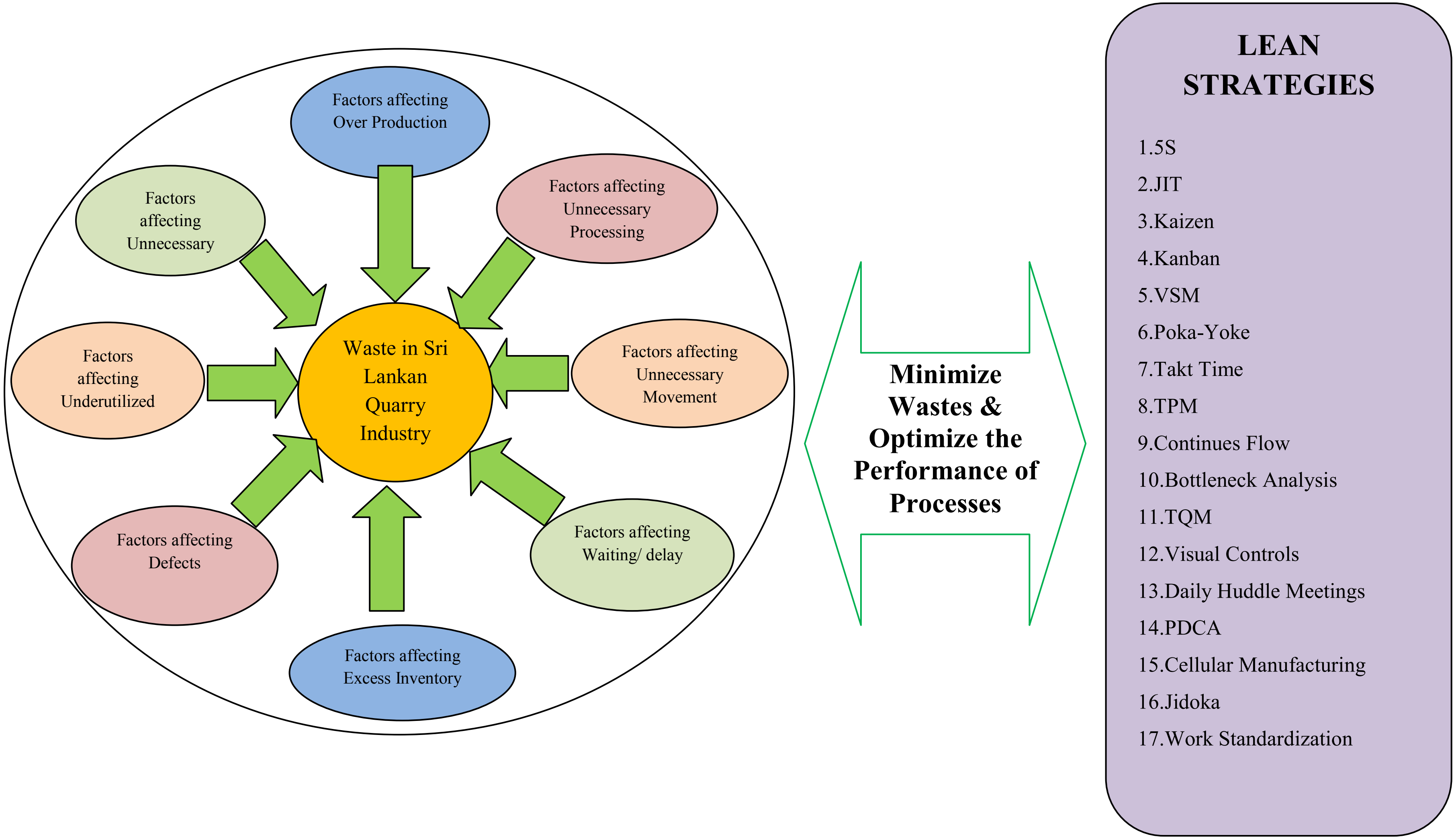

Figure 2.20: Conceptual Model

CHAPTER 03

3. RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the significance of the research study and research process. The research process includes research approach, research design, research technique, data collection and the data analysis methods.

3.2 Research Approach

According to Fellows and Lui (2003); research approaches are classified mainly into two, i.e. quantitative and qualitative. Quantitative approach tend to relate to positivism and seek to gather realistic data and to study relationships between facts and how such facts and relationships accord with theories and the findings of any research executed previously. Quantitative approach basically includes survey researches and experimental researches. Using a qualitative approach the researcher will study whole population as individuals or groups and could be able to identify beliefs, understandings, opinions, and views of people. Case study research, ethnography, action research and grounded theory approach can be taken under qualitative approaches (Fellows &Lui, 2003).

The aim of this research is to identify lean strategies to minimize waste in Sri Lankan quarry industry. Therefore, it needs to identify secondary as well as primary information to answer the research problem. Since, qualitative research can help to interpret and better understand the complex reality of a given situation, qualitative approach was selected as the research approach.

The case study methodology will be the most appropriate for this study as it delivers both the richness and depth of information not usually offered by other qualitative methodologies, and as having the ability to capture many variables with the aim of identify how a complex set of conditions come together to produce a particular manifestation (Hancock, 1998). Furthermore, Yin (2009) found that, the use of the case study methodology is appropriate when organisational and managerial issues need to be examined.

Further the case study method is the best suited approach when the research problem comprises of “how” and “why” questions (Yin, 2009). The research question of this study is “How to apply lean concept to minimize waste in Sri Lankan mining industry?”

Therefore, case study research method was selected for this research among the several types of research methods in qualitative research approach,

3.3 Case Study Design

According to Yin (2009), a case study is an “empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident”. Ragin and Beker (1992 cited in Patton and Appelbaum, 2003) stated that case studies are based on analytic generalization rather than statistical generalization. Case studies can involve either single or multiple cases, and numerous levels of analysis (Yin, 2009). Especially in case study design there are two aspects to be considered. Those are the unit of analysis and the case selection. In case study approach, sample is a purposive sample where researcher obtains a sample and it should be uniquely suited to the intent of the study. The case study designing procedure including identification of unit of analysis and selection of cases is emphasized in below.

3.3.1 Identification of Unit of Analysis

Identification of ‘unit of analysis’ or the ‘case’ is of primary important factor in any research design and it is related to the way the initial questions have been defined. This can be individual, an organization, a process or a project (Yin, 2009).

This study aimed to identify lean strategies to minimize wastes in Sri Lankan quarry industry. Therefore, the unit of analysis or the case in this research is industrial quarry projects in Sri Lanka.

3.3.2 Case Selection

Case studies can be regarded as either single or multiple case designs (Yin, 2009). Multiple case studies allow the researcher to explore differences within and between cases. The goal is to replicate findings across the cases to draw comparisons (Yin, 2003).The evidence from multiple cases is often considered more compelling, and the overall study is therefore regarded as being stronger (Herriott & Firestone, 1983). According to Yin (2003), a single case study can be adapted in situations like a critical test of existing theory, a representative or typical case, a rare or unique circumstance, a longitudinal purpose and a revelatory.

Industrial quarry project is not a unique case and it should be identified lean strategies to identified wastes in quarry projects. Therefore multiple case study design was selected for this study to increase the strength of the overall study. According to Ramanathan (2008), the minimum cases for multiple case study design should fall between two to four, and ten to fifteen as the maximum. Therefore, three industrial quarry projects which are under IML A category (large scale) was selected under the multiple case study design with time constraints and convenience. All selected quarries were owned by the private sector, because only private sector involve to the industrial quarry projects/ aggregates mining industry in Sri Lanka.

3.4 Data Collection

Under the case study approach, Yin (2003) identifies six sources to collect data: Documents, archival records, interviews, direct observations, participant observation and physical artifacts. Among these techniques, interviews were selected as the main data collection tool, while archival records and observations are used where it is necessary.

3.4.1 Interviews

Interviews can be structured, semi-structured and unstructured depending on whether the interviewer is neutral or actively involved in the process (Sekaran, 2003). In this study, interviews were carried out in semi- structured manner, as it allowed questioning appropriately, according to the circumstances, and thus any doubts could clarified by repeating and rephrasing the questions and assuring that the respondents understood the questions properly (Sekaran, 2003). In addition, if the interviews were carried out face to face, it allows identifying the non-verbal cues of the respondent which helps to understand his mentality (Sekaran, 2003).

Therefore, interview guide was developed to collect the relevant data and information from the interviews, while more preference was given for open ended questions to enhance the richness of the information collected. This interview guideline was developed with reference to the literature findings and the aim and objectives of the study. The interview guideline is attached as Annexure A.

3.4.1.1 Interview Structure

Interview was structured according to the above mentioned interview guideline and it was prepared under 3 parts. Part 1 mainly helps to identify the respondent. Part 2 included 3 sections and that helps to identify the general information of the project site including exploitation and processing stages of the industrial quarry project. Part 3 include the questions to identify factors affecting wastes under main eight (08) wastes in Sri Lankan quarry industry and strategies to minimize those factors. That section comprised 8 sub sections of wastes which are identified in the literature survey.

3.4.1.2 Interview Process

The research scope is limited to the exploitation and processing stages of the industrial quarry projects. Therefore, employees who are working in these two sections are key consideration in this study for interview process. The interviews were conducted with five participants of each case; consisting of one Manager, two from exploitation/ quarrying stage and two from processing/ crushing stage. Altogether, 15 interviews were conducted and the composition of the respondents selected for the interviews are indicated in Table 4.2 in Chapter 04.

During the interviewing, note taking and voice recording (with permission of the interviewee) were done to maintain the accuracy and prevent loosing data during data collection. Ultimately, interview transcripts were developed from the data gathered during data collection phase (see Appendix B for an example of interview transcript). To maintain the confidentiality, actual names of the selected organizations and the interviewees were not revealed in this report or any other document relating to this study.

3.5 Data Analysis

Qualitative data analysis comprises of three major steps i.e. data reduction, data displaying and conclusion drawings (Miles and Huberman, 1994). Data reduction is a process of selecting, focusing, simplifying, abstracting, and transforming data that appear in written-up field notes or transcriptions. Data displaying is organized, compressed assembly of information that permits conclusion drawing. Conclusion drawings are the interpretation of the researcher that will draw the meanings from displaying data (Miles and Huberman, 1994).

Content analysis is used as a data reduction technique for the study and that is used to analysis of the contents of data under the main themes that emerge from the responses given by the interviewees. Then cross-case analysis was executed to identify the inter-relationships between the cases and to produce write-ups made by analyzing similarities of cases.

According to Miles and Huberman (1994), data displaying capabilities of content analysis is always a problematic issue, even though it enables better interpretation of qualitative data. To overcome this shortcoming of the content analysis techniques, data displaying techniques such as tables and tree node models creates from the NVivo software are used for this study. These displaying techniques are also helped to increase the effectiveness of the cross-case analysis.

Finally the Cognitive mapping technique is used to map the identified factors affecting wastes under main eight (08) wastes in Sri Lankan industrial quarry projects and crates the frame work using lean strategies to minimize wastes in Sri Lankan quarry industry.

3.6 Summary

This chapter is focused on summarizing the research design and methodology adopted in this study. Qualitative research approach was selected as the research approach of this study while case study method was selected as the research methodology. Semi structured interview techniques is the main data collection techniques of this study and observations are used where it is necessary. Content analysis, tables and cognitive mapping techniques were explained here as the main data analytical techniques.

Chapter four will be focused on research findings and analysis of collected data.

CHAPTER 04

4. DATA ANALYSIS AND FINDINGS

4.1 Introduction

The previous chapter described the research process and the methodology. This chapter presents and discusses the findings of semi-structured interviews, in accordance with the methodology. Hence, the aim of this chapter is to present the research findings of the empirical investigation.

4.2 Overview of the Cases

Three cases were selected for the data collection of this study. Large scale industrial quarry projects, which are having the production capacity over 3000 cubes per month and those are having a managerial setup were selected for the core study. Therefore, three IML 'A'category quarry sites located in Western province and operating by well recognise local companies were selected for this study. Table 4.1 demonstrates brief description about the selected cases.

Table 4.1: Case Description

Case	Type of the organization and the project	Location	Project duration to present	License category	No. of Crusher plants and their capacity	Total monthly production of the project
A	Owned by the private sector. Produce rock boulders, ABC, asphalt aggregate and concrete aggregate to use local construction works carried out by the same company and not to sell outside customers.	Kaluthara District in Western Province	11 years	IML – A	Only one crusher plant for the project and their capacity is 150 t/hr	3000 – 4000 cubes
B	Owned by the private sector. Supply different type of aggregates and rock boulders to the outside customers for the local construction project.	Colombo District in Western Province	15 years	IML – A	Only one crusher plant for the project and their capacity is 100 - 120 t/hr	4000 -5000 cubes
C	Owned by the private sector. Supply different type of aggregates to the main construction firms in Sri Lanka	Colombo District in Western Province	30 years	IML – A	Three crusher plants for the project and each plants capacity is 45 cubes/hr.	10,000 – 12,000 cubes

4.3 Profile of Interviews

The interviews were conducted with five participants of each case; consisting of one Manager, two from exploitation/ quarrying stage and two from processing/ crushing stage. Altogether, 15 interviews were conducted and the profile of the interviews is demonstrated in Table 4.2.

Table 4.2: Profile of Interviews

Case	Respondent	Designation	Experience	Remark
A	A1	Site Manager	08 years	Managerial Level
	A2	Blasting Supervisor	05 years	Exploitation Stage
	A3	Crusher Forman	12 years	Processing Stage
	A4	Crusher Operator	04 years	Processing Stage
	A5	Machine Operator	01 year	Exploitation Stage
B	B1	General Manager	20 years	Managerial Level
	B2	Mining Engineer	05 years	Exploitation Stage
	B3	Blasting Forman	01 year	Exploitation Stage
	B4	Crusher Forman	10 years	Processing Stage
	B5	Crusher Helper	03 years	Processing Stage
C	C1	Site Manager	11 years	Managerial Level
	C2	Mining Engineer	08 years	Exploitation Stage
	C3	Crusher Supervisor	22 years	Processing Stage
	C4	Blaster	15 years	Exploitation Stage
	C5	Machine Operator	04 years	Processing Stage

4.4 Cross Case Analysis

Cross case analysis was carried out separately under main eight wastes identified in the literature survey. Factors affecting wastes identified under each main waste category in the case study were categorised as avoidable and unavoidable. Number of respondent for each factors were also indicated along with them. Annex C illustrates the above mentioned details for easy reference. The table of Annex C also helps to identify the respondent view regarding the main wastes, under two themes as "is there any waste" and "consider it as a waste".

4.4.1 Waste in Sri Lankan Quarry Industry

Above findings indicated in the table of Annex C were summarised more precisely and effectively under three cases. Here, if more than 2 respondents had pointed out one factor it was identified as a general factor affecting waste of the selected case or quarry site. That mean equal or more than 60% respondent answers were considered to identify factor affecting wastes in each quarry site.

Table 4.3 demonstrates the summarised factors affecting waste under main waste categories in each quarry site (using Annex C) which were identified after analysis of respondents' opinions as explained above. In this table;
(√) :- For responses more than two (02) under each case for one factor
(x) :- For responses equal or less than two (02) under each case for one factor

The reasons/factors identified in; all three cases were categorized as high critical factors generating wastes, two cases were categorized as critical factors and non critical factors are those that appear in only one case. Finally lean strategies were introduced only for the high critical and critical factors causing wastes which were under avoidable category.

Table 4.3: Identified factors affecting wastes in industrial aggregate mining project in Sri Lanka

	Wastes/ NVAA	**Factors affecting wastes**	**Case A**	**Case B**	**Case C**	**Remark**
1	Over Production	**Avoidable**				
		i) Breakdowns & maintenance of machines, plants & vehicle	√	√	√	High Critical
		Unavoidable				
		ii) Bad weather	√	√	√	High Critical
		iii) Uneven fluctuation of the daily demand	√	√	√	High Critical

2	Waiting/ delay	**Avoidable**				
		i) Breakdowns & maintenance of machines, plants & vehicle	√	√	√	High Critical
		ii) Non maintenance of benches	X	√	X	Not critical
		iii) Poor site layout	X	X	√	Not critical
		iv) Non availability of explosives	X	X	X	Not critical
		v) Delay of information & instruction	x	X	X	Not critical
		Unavoidable				
		vi) Bad weather	√	√	√	High Critical
		vii) Safety issue in the blasting time	√	√	√	High Critical
3	Unnecessary Transportation	**Avoidable**				
		i)Double handling/ intermediate storage	√	√	√	High Critical
		ii) Non availability of workshop	√	X	X	Not critical
		Unavoidable	No			
4	Unnecessary Processing	**Avoidable**				
		i) Old plant, machine& vehicle	√	√	√	High Critical
		ii) Inappropriate gangue size	√	√	√	High Critical
		iii) Non maintenance of benches	x	√	X	Not critical
		Unavoidable				
		i) Bore holes fill with water	√	√	√	High Critical
5	Excess Inventories	**Avoidable**				
		i)Excess finished products	√	√	√	High Critical
		ii)Excess machines/ vehicles	X	X	X	Not critical
		Unavoidable	No			
6	Unnecessary Movement/ Motion	**Avoidable**				
		i) Unnecessary workers travel looking for parts, tools, helps	√	√	√	High Critical
		ii) Unnecessarymachines travel within site for small repairs	x	√	√	Critical
		iii)Mucking start from wrong direction	x	X	X	Not critical
		iv)Machines travel due to security issues.	x	X	X	Not critical
		Unavoidable	No			

7	Defects	**Avoidable**				
		i)Damage of Screen	√	√	√	High Critical
		ii)Sudden variation of crusher setting	√	√	√	High Critical
		iii)Uneven loading	√	X	√	Critical
		iv)Lack of proper supervision & management	√	√	X	Critical
		v)Not properly remove overburden and weathered rock layers	x	X	X	Not critical
		vi)Fault of excavator operators	x	X	X	Not critical
		Unavoidable				
		vii)Raining	√	√	√	High Critical
		viii) Scrap crusher production because customer demanded mix design does not tally with crusher.	x	X	X	Not critical
8	Underutilized People	**Avoidable**				
		i)Unsatisfied monthly salary and/ or Lack of salary increments/ bones/ incentives	√	√	√	High Critical
		ii)No facilitated & comfortable office space/accommodations/controlling rooms	√	√	√	High Critical
		iii)Lack of safety at site	√	√	√	High Critical
		iv)Bad appearance of site	√	X	√	Critical
		v)Inappropriate gangue size	√	√	X	Critical
		vi)No promotion scheme	X	X	√	Not critical
		vii) Lack of admiration	X	X	X	Not critical
		viii) Lack of proper supervision& management	X	X	X	Not critical
		ix)Lack of employee skill development programme	X	X	X	Not critical
		x)Lack of head office's concern on mining site	X	X	X	Not critical
		xi)Lack of performance maintaining system	X	X	X	Not critical
		Unavoidable	No			

Identified factors affecting wastes are discussed in below under main eight waste categories. Factors those are not highlighted more than two respondents in all cases (Table 4.3 & Annex C), are not discussed.

4.4.1.1 Over Production Waste

It was observed in all cases that they normally keep excess quarry and crusher production. That was proven because all 15 respondents' answers for the question "Is there any excess quarry and/ or crusher production?" were "yes" (Refer Annex C). That means there is an overproduction waste in all three selected cases.

According to respondent A1 *"rock material is a critical one of the supply chain of the construction project and there is a machine fleet demanding continues material supply for the project. Therefore we should have enough quantity of aggregate materials at any time as the project expect. Daily demand of any construction project can vary and is not same in every day. Therefore excess quarry production should be maintained. However it is difficult to give an exact figure for quantity that should be maintained because it depends on time. Nevertheless we target to achieve double production compared with demand"*. Further respondent B1 stated that *"they normally produce 500cubes/month as their excess crusher production*". Also respondent C2 stated that *"their excess quarry production is 50cubes/day and they try to keep 1000 cubes/month as their excess crusher production"*.

Every respondent in all three cases accepted their excess production, however no one accepted it as a waste (Refer Annex C). All of them give reasonable answers to above question and explains the need for excess quarry and crusher production. However, all these differently expressed answers can be categorized under three main reasons. And these are identified as factors affecting waste of over production. Figure 4.1 shows the factors affecting on over production as encountered by the respondents and Table 4.4 illustrates the responses of respondents.

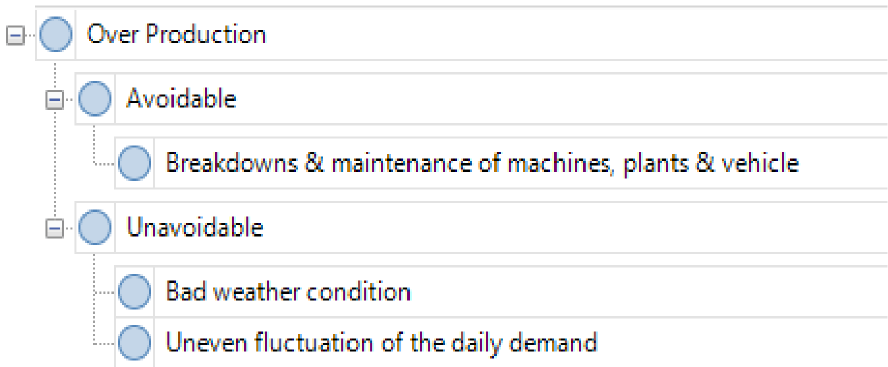

Figure 4.1: Factors affecting Over Production

Table 4.4: Respondents' responses on factors affecting over production

Factors	Case A					Case B					Case C					
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	
Avoidable																
i) Breakdowns & maintenance of machines, plants & vehicle	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	HC
Unavoidable																
ii) Bad weather condition	√	√	√	X	√	√	√	X	√	√	√	√	√	√	√	HC
iii) Uneven fluctuation of the daily demand	√	√	√	X	X	√	√	X	√	X	√	√	√	X	X	HC

- **Breakdown & Maintenance of Machines, Plants and Vehicles**

Excavators, loaders, rock breakers, air compressors, track/ crawler drill machines, pneumatic hand held drilling machines, crusher plants, generators, dump trucks, light trucks, tractors, water bowsers, diesel bowsers are normally being used under exploitation and processing stages of Sri Lankan quarry industry.

Interview results demonstrated that, breakdown and maintenance of above machinery, plants and vehicles cause to keep excess quarry and crusher production. According to Table 4.4 all 15 respondents' opinions were that, it is necessary to keep excess production in order to meet demand in machines, plants, vehicles breakdown and maintenance.

Respondent A1 stated that, *"breakdown can happen even if those are new. In some days all excavators in their site have been broken down. In that situation excess quarry and crusher production helped to continue supply smoothly"*. The further expressed his recent experience regarding this, *"Jaw unit of the crusher plant had been broken down for 3 months, but still has not repaired it due to unavailability of parts in the country. Therefore they use their excess crusher production for one week until their mobile crusher was delivered to the site"*.

According to the respondent, maintenance work of some machinery takes some considerable time. Therefore in order to face a similar situation, it is necessary to keep excess production. However, from the strategies illustrated during the interview, it was realized that this is a high critical but avoidable factors affecting waste.

- **Bad Weather**

Quarry site belongs to one of the surface mining category and normally operates asopen pit or hillside excavation in the rock outcrops of an area (Herath, 2010). So it is clear that this is an open environment process and therefore, weather condition is very important to execute the quarrying and crushing activities smoothly. Bad weather conditions like raining and lightning mainly effect to all processes in quarry industry. All activities have to be stopped at the time of above mentioned weather conditions or by considering safety issues. In the monsoon seasons, there is continues raining for about 2-3 days and quarry have to be completely closed until the rain stopped.

Case C is operating as an open-pit mine, but other two is operating as hillside excavation quarries. This quarry site has flood in the rainy season and they have to wait until the flood level lowers to start the quarrying activities again. It will take additional 2-3 days even if they use water pumps.

Therefore 13 out of 15 respondent answers stated the necessity to maintain excess production to face bad weather condition (Table 4.4. and Annex C). However they further stated that this is an unavoidable factors affecting waste.

- **Uneven Fluctuation of the Daily Demand**

Three selected cases (quarries) supply material to number of construction projects and do not depend on single project. The daily demand of those projects can be fluctuated even though the total demand has calculated. According to some respondents, in some days they have to supply more than their daily production. In this situation excess production was used to keep good customer satisfaction. Due to high competition of the aggregate market, customer satisfaction must be maintained to achieve the stability of the company. Therefore "Uneven fluctuation of the daily demand" is one of the factors affecting overproduction and that is unavoidable.

4.4.1.2 Waiting / Delay Waste

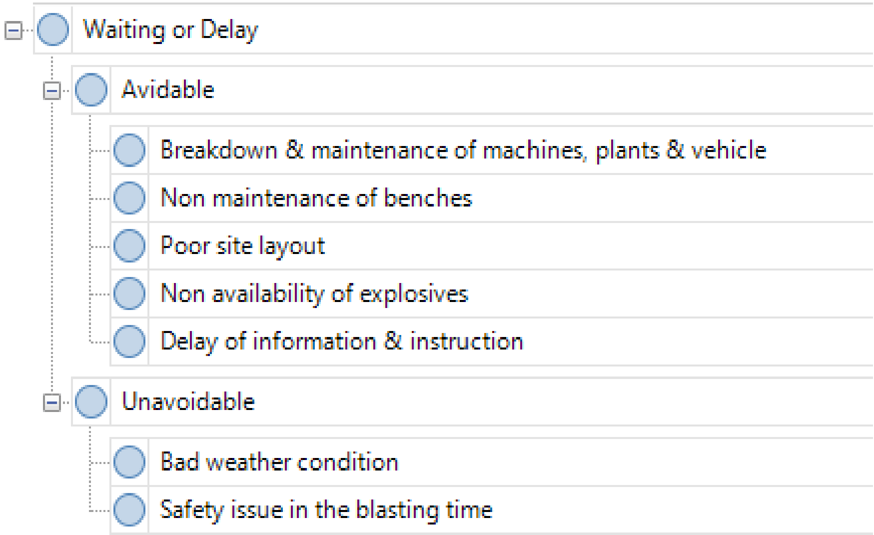

Figure 4.2: Factors affecting Waiting/ Delay Wastes

Interviews were directed to find any delays/ waiting in exploitation and processing stages of the quarry industry. Therefore, it was based to find any delays due to machine and /or plant and / or vehicle breakdown and / or maintenance, waiting for materials, waiting for equipment / tools, waiting for information/ instruction and present site layout. Also the interview guidelines were targeted to find any delays between subsequent processing steps together with suitable strategies to reduce delays.

According to all 15 respondents' answers (Annex C), there were factors affecting waiting /delay wastes. Identified factors under above waste type illustrate in Figure 4.2 and responses of respondents are shown in Table 4.5.

Table 4.5: Respondents' responses on factors affecting waiting/ delay waste

Factors	Case A					Case B					Case C					
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	
Avoidable																
i) Machines and plant breakdowns	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	HC
ii) Non maintenance of benches	X	X	X	X	X	X	√	√	√	X	X	X	X	X	X	NC
iii) Poor site layout	X	X	X	X	X	X	X	X	X	X	X	√	√	√	X	NC
iv) Non availability of explosives	X	X	X	X	X	X	X	X	X	X	X	X	X	√	X	NC
v) Delay of information & instruction	X	X	X	X	X	X	X	X	X	X	X	X	√	√	X	NC
Unavoidable																
vi) Bad weather condition	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	HC
vii) Safety issue in the blasting time	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	HC

- **Breakdown & Maintenance of Machines, Plants and Vehicles**

This was identified as factor affecting waiting / delays waste, same as over production waste. Also this was categorized as highly critical factor because all respondents in all 3 cases highlighted that breakdown and maintenance of machines, plants and vehicles cause various delays in their sites (Table 4.5). Especially, this affect to create delays between subsequent processing steps in the process.

According to respondents B1 and B4 *"due to the breakdown of excavators, breakers and dump trucks in time to time some subsequent processing steps i.e. breaking – loading, loading – transporting and transporting - processing were delayed in their site for about 1 – 4 hour in some days.* Track drill machine is mainly used in the selected case C for their drilling process, but it breaks down frequently because it is old more than 10 years. According to respondent C4, *"when the track drilling machine breaks down drilling operation gets late. Normally it takes at least half day* *to repair it back to the running condition. In this situation blasting is also delayed by at least one day".* As explain under item 4.4.1.1 the crusher plant of the case A was broken down 3 months before, but still not repaired and the processing of aggregate were delayed 2 weeks until the mobile crusher was delivered to the site.

Machine maintenance also takes some considerable time. Excavators and breakers should be serviced after every 250 hrs, 500hrs and 1000 hrs regularly. For 250hr and 500hr services takes about 2 hours but for the full service in every 1000hr takes 5-6 hrs. Therefore this also affects to the overall process and cause to delay some activities in the process. Other machines and vehicles should also be serviced regularly and for that also takes some time.

Therefore, breakdown and maintenance of machines, plants and vehicles critically affect for the delay of various activities in the process and also in the overall process. However this was categorized under avoidable factors because of the suggestions came from respondent as strategies to minimize those drawbacks.

- **Non Maintenance of Benches**

This is a special issue only for the selected case B. Normally industrial quarry projects should be developed according to the bench system in order to avoid unsuitable working conditions. This particular project does not consider this issue and they do their drilling and blasting without maintaining bench system. Therefore, up to now, their quarry site is about 85 m height and directly steep and 3 respondents of case B highlighted this as a factor affecting waiting waste (Table 4.5). Currently their drilling and blasting activities get delay owing to the difficulty to reach drilling and blasting locations. Also extra time is needed for those activities due to unsuitable working condition. Since this is only for the case B, this was categorized as a "Not critical" and avoidable factor.

- **Poor Site Layout**

This is also a special case for selected case C. There are three crusher plants in this site. Even the site has enough space to install three plants in same land closed to each other only two plants had been installed in land which is closed to the quarry site and has a distance of about 100 m from the quarry site. The third plant had been installed in a separate land which is having a distance of about 300 m from the quarry site. Therefore 3 respondents of the case C show that transporting – processing is getting delay due to above mentioned improper site layout (Table 4.5). This is also categorized under avoidable non critical factor affecting waste.

- **Bad Weather**

The effect of the bad weather condition to operate aggregate mining project was discussed under 4.4.1.1 It is clear that the bad weather, specially raining cause to stop all the activities in the process, generating a delay. Therefore all respondents of all cases stated that bad weather causes delay in activities in the overall process (Table 4.5). So this is a high critical factor affecting waste and cannot be avoided.

- **Safety Issue in the Blasting Time**

At the firing of blasting, all workers, machinery and vehicles should be evacuated to a safer distance to prevent fly rock incidents from the blast. At least 200m safety distance should be kept around the blasting location, but that distance can be changed from time to time according to the decision of Engineer or blasting Forman. Also the crushing plants should be stopped, if it is closed to the quarry site. If Crusher Plant in safety distance is also stopped due to the stopping of material transport from the quarry. According to respondents' answers of all 3 cases, minimum of 30-45 minutes takes to complete the firing of blasts. Therefore during this time all activities are getting delayed. However, this was identified as a high critical factor affecting which cannot be avoided (Refer Table 4.5).

4.4.1.3 Unnecessary Transportation Waste

Commonly using internal and external transportation methods were identified in the quarry industry. Those are shown below separately.

<u>Internal transportation method</u>

1. Rock transportation from quarry to crusher plant using dump trucks.

2. Aggregate transportation from crusher plant to stock piling site using tractors or dump trucks.
3. Explosive transportation from magazine to quarry using a tractor or a cab.
4. Diesel bowser travel from yard to site.
5. Water bowser travel along access roads and other dust generating areas to spray water.

<u>External transportation method</u>

1. Quarry and crusher production transportation from site to customers using dump truck and light trucks.
2. Explosive transportation from nearest police station to site using a cab.
3. Diesel transportation from nearest fuel station to site.
4. Materials which are used to maintain site, machines and vehicles are transported to site.

14 respondents out of 15 accepted that there were unnecessary transportation in their sites and all of them view this is as a waste (Annex C). Following were identified as the reasons for unnecessary transportation and those are discussed below as factors affecting unnecessary transportation. Figure 4.3 shows the above factors under avoidable and unavoidable separately and the Table 4.6 clearly indicates response of each respondents.

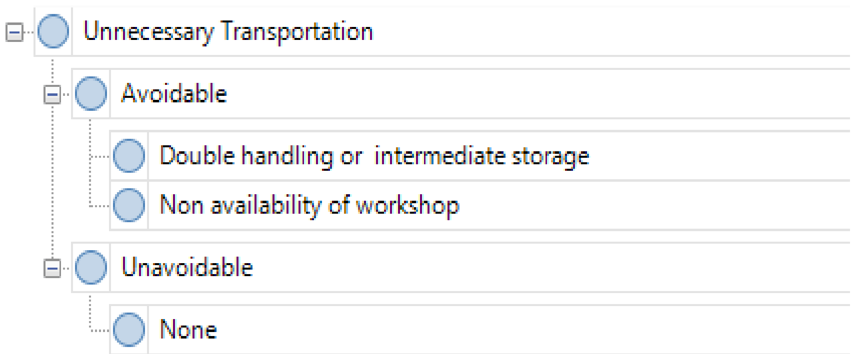

Figure 4.3: Factors affecting Unnecessary Transportation

Table 4.6: Respondents' responses on factors affecting unnecessary transportation

Factors	Case A					Case B					Case C					
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	
Avoidable																
i)Double handling/ intermediate storage	√	√	√	√	√	√	√	X	√	X	√	√	√	√	√	HC
ii) Non availability of workshop	√	√	√	√	√	X	X	X	X	X	X	X	X	X	X	NC
Unavoidable	No					No					No					

- **Double Handling / Intermediate storage**

It was identified that space is not enough in the crushing plant area in all selected cases. Therefore it causes to increase the double handling and intermediate storage. According to respondent C3 *"due to low space of the crusher stock piles, excess material is stocked in another selected stock piling area having distance of about 75m from the crusher plant. He further stated that during a certain period if the customer demands only for ¾ inch aggregate, remaining dust material accumulates. In this type of situation remaining materials have to be removed from the stock pile if it is having some considerable space".* For this intermediate storage, extra machines and dump trucks have to be used for material transportation to another stock pile. This was identified in all cases as a factor affects unnecessary transportation waste. Therefore it is a high critical factor (Refer Table 4.6). It is clear that the intermediate storage is reason for the unnecessary transportation, therefore this should be avoidable.

- **Non Availability of Workshop**

This was only identified in case A and all respondents answered that this is one of the main reason for the unnecessary transportation (Refer Table 4.6). They don't have a workshop for machine and vehicle repair. At least a welding plant is not available in their site. Therefore, even for the small repairs, the damaged parts have to be sent to their main workshop, which is 60km away from the site. However, if the site has a suitable workshop, the company can save that transportation cost and time. Therefore this is an unnecessary transportation, but a unique issue for the case A. Therefore this was categorized as a "not critical factor", but can be avoidable.

4.4.1.4 Unnecessary Processing Wastes

Interviews were target to find out whether there was any unnecessary time wasting for any activities in the process. Therefore average time required and actual time was taken each stage of the process separately. If both times do not tally with each other, it shows that there is an unnecessary processing waste behind them. Reasons for not tallying of time and strategies to be taken to avoid them are discussed. If the average and current time tally with each other, strategies that were in used already were also recorded (Refer Annex A). As well as production/ processing steps in selected cases were examined to identify any inappropriate steps, but none were found at any site. However, all respondent's opinions were that there was some unnecessary processing waste in their sites (refer Annex C). According to the view of respondents' (refer Table 4.7) following factors affecting unnecessary processing were identified (refer Figure 4.4) and those are explained below.

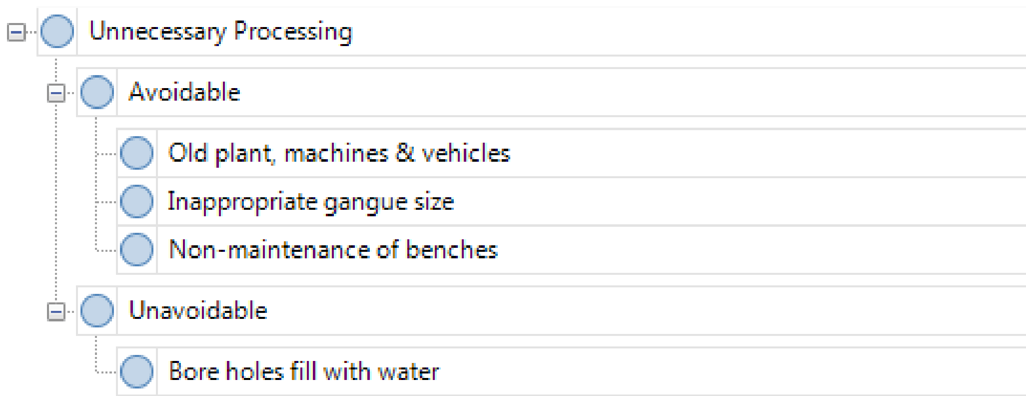

Figure 4.4: Factors affecting Unnecessary Processing

Table 4.7: Factors affecting unnecessary processing

Factors	Case A					Case B					Case C					
	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**C5**	
Avoidable																
i) Old plants, machines & vehicles	√	√	√	√	X	X	√	X	√	√	√	√	√	√	√	HC
ii) Inappropriate gangue size	√	X	√	√	√	X	X	√	√	√	X	√	√	√	√	HC
iii) Non maintenance of benches	X	X	X	X	X	X	√	√	√	√	X	X	X	X	X	NC
Unavoidable																
iv)Bore holes fill with water	√	√	√	X	√	√	√	√	√	√	√	√	√	√	√	HC

- **Old Plant, Machine and Vehicle**

Normally efficiency of all plant, machine and vehicle reduce with time. Therefore, to keep the maximum efficiency, it is necessary to maintain them with regular service. Otherwise their efficiency will be reduced with the running time. However, it was difficult to maintain their normal competence after the lifetime.

According to respondent C2 and C4 *"Average time for drilling one hole of 20feet depth is 7-10minutes, but currently it takes about 12-15minutesbecause their track drill machine is very old"*. Also according to respondent B4 *"they used about 10 year old crusher plant to take aggregate. Currently it takes about 15minutes to crush one three cube dump truck load, if the average time for it is 8minutes"*.The crusher plants used in case C are very old and therefore those took some extra time to aggregate crushing. According to the crusher supervisor (C3), the average capacity of their crushing plant is 45 -55 cube/hr, but currently this is reduced to 35 - 40 cube/hr.

Therefore old plants, machines and vehicles were identified as a factor affecting under unnecessary processing waste in all three cases (Table 4.7). So it was categorized as high critical factor under avoidable category.

- **Inappropriate Gangue Size**

Inappropriate gangue size was identified as another main cause behind unnecessary processing in all three cases. Therefore this was categorized under high critical avoidable cause (Refer Table 4.7).

Especially this was highlighted by the respondents below supervisor level. According to respondent C4 *"blasting gangue of their site is only five. According to licence condition, diameter of 64mm and depth of 20ft 100 holes can be fired per day. That should be 5 blasts with 20 holes per each. Firing time should be given as 10 00hr to 14 00hr by the license authorities, but it was difficult to complete the explosive charging and firing the blasts before 14 00hr. Therefore, some days it was taken extra 1-2 hr to complete the charging and blasting activities, but it was a violation of licenses conditions. Also, some days some holes remain without being charged, because of insufficient time to complete. Therefore it is a requirement to increase the gangue size".*

According to the opinions of respondents, this was same in all stages, but specially highlighted in stages like drilling, explosive charging & blasting, crushing. Therefore some extra time have to be waste to complete some task due to inappropriate gangue size.

- **Non Maintenance of Benches**

This is only identified in case B (Table 4.7) as explain in item 4.4.1.2. According to4 respondents out of 5 of case B, not maintaining the proper bench system causes extra time especially for drilling and blasting activities.

According to the explanation of respondent B3 *"normally spent 5-6 minutes to drill 10feet hole, but now that is exceeded due to height of the compressor hose. Compressors were currently placed in quarry floor without having benches.*

Therefore air pressure is reduced with the height and drilling capacity is reduced due to that. Also some extra time have to be wasted for explosive charging because of the unsuitable working condition."

This was categorized as a not critical factor affecting waste under avoidable category.

- **Bore Hole Fill with Water**

Drilled bore holes can be filled with water due to raining. Also seepage is another cause to fill the drilled holes with water. However, before charge the explosives, the holes should be cleaned to remove water. This is called as "blow out" and compressed air is used for that. This time for blow out add extra time for the blasting process. Therefore holes being filled with water are one reason for unnecessary processing.

Respondent C4 explain this issue as *"to charge 20holes of 64mm diameter and 20ft depth, normally takes 1hr in their site, but it takes around 2 hr in some days because holes are filled with water"*. Therefore 14 out of 15 respondents highlighted this and therefore this was identified as a high critical factor affecting waste, but categorized under unavoidable sub factor (Table 4.7).

4.4.1.5 Excess Inventory Waste

Storage of raw materials, intermediate and finished products unnecessarily is identified as excess inventory wastes (*Kilpatrick, 2003)*. Currently using and minimum required machineries and materials to achieve present production target were recorded from the respondents (Refer Annex A). Information acquired from section 4.4.1.1 (Under over production wastes) of Annex A was used to identified about any unnecessary finished products. According to the view of respondents' following two factors affecting excess inventory waste were identified (Refer Figure 4.5) and those are explained below.

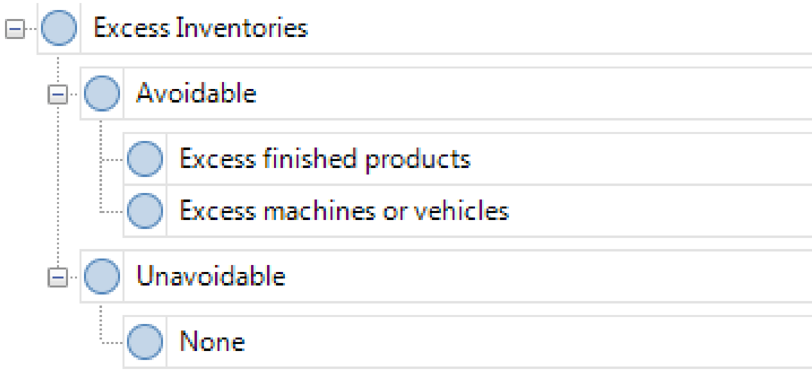

Figure 4.5: Factors affecting Wastes on Excess Inventories

Opinions of the respondents in all three cases regarding the factor affecting waste in excess inventories are shown in following Table 4.8.

Table 4.8: Respondents' responses on factors affecting waste under excess inventories

Factors	**Case A**					**Case B**					**Case C**					
	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**C5**	
Avoidable																
i)Excess finished products	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	HC
ii)Excess machines/ vehicles	√	X	√	X	X	X	X	X	X	X	X	X	X	X	X	NC
Unavoidable	No					No					No					

➢ Excess Finished Products

As discussed under over production waste (Item 4.4.1.1), it was observed in all cases that they normally keep excess quarry and crusher production. According to all 15 respondents' answers normally they maintain excess finished products. Therefore this was identified as a high critical and avoidable factor affecting waste (Refer Table 4.8).

➢ **Excess Machines/ Vehicles**

According to respondents initial purchasing costs as well as maintenance cost of the mining machineries are very high. Therefore, it is difficult to keep excess machines. Also the frequently using materials i.e. drill bits and rods, tooth and tooth pin of excavator buckets, buckets' shanks, track plates, required nuts and bolts are only stored in little amounts to use as necessary and were not stored unnecessarily. Also materials like fuel, explosives and lubricant that are being used daily are stored according to the weekly requirement. Others are not stored within the site and are purchased time to time as per the requirement. According to the responses of respondents, 13 out of 15 answered (Annex C) that there were no any excess inventories in their sites.

Only 2 respondents highlighted that there was an excess inventory due to excess machines (Table 4.8). That was identified in the case A and mentioned by A1 and A3. There was a Volvo 5.5 cubes dump truck for rock transport from quarry to crusher plant, but its capacity and fuel consumption are very high. Therefore, it is better to use 3cubes dump trucks (2 nos.) which were used previously instead of above large dump truck. However this was categorised as a non-critical factor affecting waste because only two respondents mentioned about this.

4.4.1.6 Unnecessary movement/ motion waste

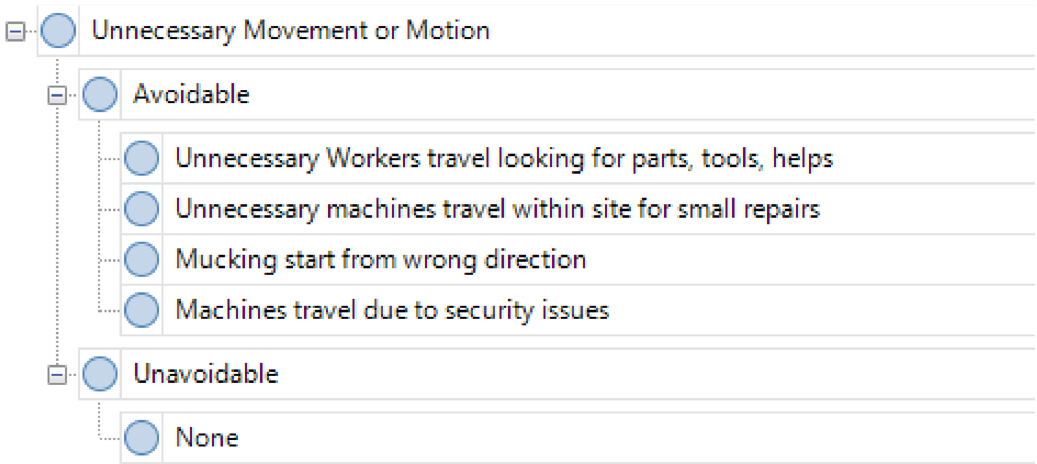

Figure 4.6: Factors affecting Wastes under Unnecessary Movement / Motion

Table 4.9: Respondents' responses on factors affecting waste under unnecessary movement / motion

Factors	**Case A**					**Case B**					**Case C**					
	A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**C1**	**C2**	**C3**	**C4**	**C5**	
Avoidable																
i) Unnecessary Workers travel looking for parts, tools, helps	√	√	√	√	√	X	√	X	√	√	X	√	√	√	√	HC
ii) Unnecessary machines travel within site for small repairs	X	X	X	X	X	X	√	X	√	√	X	√	√	√	X	C
iii)Mucking start from wrong direction	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	NC
iv)Machines travel due to security issues.	X	X	X	X	X	X	X	X	√	X	X	X	X	X	X	NC
Unavoidable	No					No					No					

Types of machinery movements and human motions in exploitation and processing stages were identified separately. Then interviewers have been questioned to identify any unnecessary machinery and human movements and/or motions. Reasons for these movements/motions and the possibility to reduce those were discussed together with relevant strategies (Annex A).

All respondents highlighted at least one unnecessary movement/ motion in their site and all of them consider the unnecessary movement/ motion as a waste (Annex C). Identified factors affecting wastes and respondents' responses for those factors shows in Figure 4.6 and Table 4.9 respectively and those are discussed below.

➢ **Unnecessary Workers Travel Looking for Parts, Tools and Helps**

This was identified as a common issue in all three cases. 12 out of 15 respondents pointed out above as a factors affecting waste under unnecessary movement (Table 4.9). At the time of machine, vehicle and plant breakdown and maintenance, almost all operators, mechanics and helpers travel more than one time to their workshop and store to bring parts / tools. Also some of them normally come more than once to site office or workshop to ask for help.

According to respondent B2,*"when a machine or a vehicle breakdown occurs, operators and mechanics come to workshop and store more than once to take tools and parts because they don't have a good understanding about the issue".*Also respondent A1 stated that *"at the time of crusher plant repairing, some operators, mechanics and helpers traveled from crusher site to store several times which has a distance of about 75m. According to him reasons for those are not initially identifying reason for the breakdown and not using of record book. Also they don't have a store keeper to maintain their store well and if it is maintained properly, this type of unnecessary movements can be avoided".*

By considering the all responses, this was identified as a high critical factor affecting waste under avoidable category.

- **Unnecessary Machines Travel within Site for Small Repairs**

Unnecessary traveling of machines especially excavators and breakers should be minimized and every possible attempt to be taken to reduced it. Because it cause to wearing of parts speedily and cost will be very high to replace the parts. Also fuel consumption is considerably high and around 15L of diesel is needed for one effective machine hour of Kobelco SK 200 excavator. Therefore, it is necessary to keep the machine in optimum travelling.

This was highlighted only in cases B and C, where 3 respondents in each case pointed out their machines travel unnecessarily for small repairs (Table 4.9) and that should be minimized. Therefore this was identified as a critical factor affecting unnecessary movement/ motion under avoidable category.

According to respondent C2 *"when small breakdown occurs like breaking of a tooth pin of a excavator bucket, pull out or breaking of main pins in arm/boom/bucket/breaker unit and breaking or pull out of pin lock; the machines travel to workshop from the quarry site to repair it. But that type of repairs can be* *done in site and travelling about 150m and 100m from quarry and crusher separately can be avoided".*

In case A above type of small repairs is done at the place of breakdown happened and does not move anywhere.

4.4.1.7 Defects

Arising of quality issues in aggregate production is the defects in quarry industry. Several quality requirements are expected by the customers, but those vary with the production category and the project requirements. However, tests like Specific Gravity (SG), Sieve analysis, Flakiness Index (FI), Loss Angelies Abrasion Value (LAAV) and Aggregate Impact Value (AIV) are normally done for any production category in any project as for the requirement. These tests help to identify rock weight, grading/ size of the sample, resistance to wear and strength.

Actions that were currently taken to maintain customer required qualities, possibilities to arise quality issues in productions and strategies to be taken to eliminate those were questioned in the interview. Following reasons were identified as factors affecting defects and those are categorized under avoidable and unavoidable factors as illustrated in following Figure 4.7.

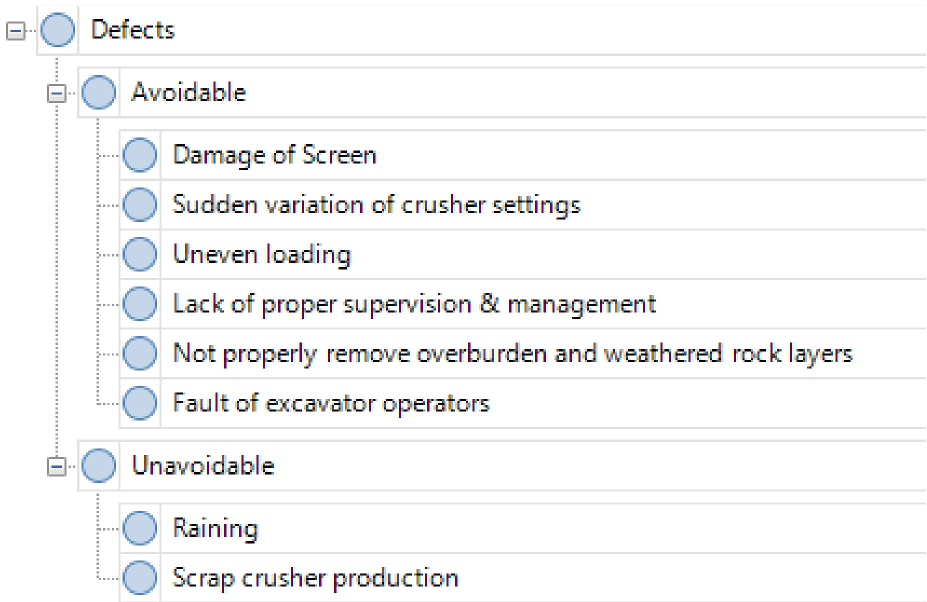

Figure 4.7: Factors affecting Defects

Above factors identified under defects were again categorized as high critical, critical and not critical factors by considering the respondents' responses. Following Table 4.10 shows the responses of respondents.

Table 4.10: Respondents' responses on factors affecting defects

Factors	Case A					Case B					Case C					
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	
Avoidable																
i)Damage of Screen	√	√	√	√	X	√	√	√	√	√	√	√	X	√	√	HC
ii)Sudden variation of crusher settings	√	X	√	√	X	√	√	X	√	X	√	√	√	X	X	HC
iii)Uneven loading	√	X	√	√	X	√	√	X	X	X	√	√	√	X	X	C
iv)Lack of proper supervision & management	√	√	√	√	√	√	√	√	√	√	√	√	X	X	X	C
v)Not properly remove overburden and weathered rock layers	X	X	X	X	X	X	X	X	X	X	X	X	√	√	X	NC
vi)Fault of excavator operators	X	X	X	X	X	X	X	X	X	X	√	√	X	X	X	NC
Unavoidable																
vii)Raining	√	√	√	√	X	√	√	X	√	√	√	√	√	√	X	HC
viii) Scrap crusher production because customer demanded mix design does not tally with crusher.	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	NC

- **Damage of Screen**

Vibrating screen with set of sieves is used to produce separate aggregate samples. Asphalt aggregates and ABC (Aggregate Base Course) are the main samples taken from the crushing plants, but as per the customer/ project requirement any kind of aggregates are produced from the crushing plants. Separate sieves are used to get separate sampling sizes. Asphalt aggregate is a mixture of separate samples. Normally samples of 0-5mm (dust), 5-10mm (chip), 10-15 (1/2 inch) and 15-20mm (3/4 inch) produces separately and mixes together by taking relevant proportion from each sample with bitumen to produces asphalt. Sieves that are having sieve size of 20mm, 15mm, 10mm and 5mm are connected to the screen for taking above samples. ABC is a mix sample of 0-37.5mm size, but it should be matched with the relevant S curve given by the customer/ project. That means relevant grading of the sample should be maintained. In addition to above 1inch, 1&1/2 inch, 2 inch samples are demanded by the local market. According to the customer requirement above mentioned asphalt aggregate is also demanded separately for the local construction works. As an example, for block works normally use dust material and for concrete use ¾ and/or 1 inch material with dust.

Oversize particles get added to the sample when sieves in screen are damaged. Due to that reason, pre planed sample size cannot be taken correctly and also unable to keep the relevant grading of the sample. Therefore it causes poor quality of the sample and leads to customer dissatisfaction.

According to respondent C1, "*larger particles get add to the sample when sieves in screen are damaged. Lack of supervision and monitoring is one reason for above issue. Also the old condition of sieves is another main reason for this issue*".

This was identified in all three cases and therefore "damage of screen" is categorized as high critical factors affecting defects under avoidable category (Refer Table 4.10).

- **Sudden Variation of Crusher Setting**

It is valuable to keep relevant crusher settings to maintain quality of aggregate productions. Because when the crusher setting is changed, relevant grading of the sample varies. Here it is especially important to maintain primary and secondary crusher setting correctly. Primary jaw crusher settings are done by adjusting the clearance between fix jaw and swing jaw. Finally its output size is matched with input size of the secondary cone crusher. Cone crusher setting is done by adjusting the space between mantel and cone cave. Both hydraulic and mechanical system is used to adjust above crusher settings. According to respondent, reasons for always changing of the crusher settings are; wear of mechanical parts, changing hydraulic pressure and old condition of the plant.

Since majority of the respondents in all three cases highlighted above issue, varying of crusher setting is identified as a high critical but avoidable factor affecting defects (Refer Table 4.10). Because this cause to change the grading of the aggregate productions, it is necessary to check sample grading randomly by doing sieve analysis test and does relevant adjustment as necessary.

- **Uneven Loading**

Loading is also important to maintain the production quality. In some dump trucks loading proportions have more small rock particles or quarry mud. When those are fed to the crusher plant small particle proportion of the sample can be higher than the required maximum. That means grading can be changed.

Normally high density particles settle at the bottom of the stock pile in crushing site. Therefore before loading to the dump trucks to supply for customers, pile should be mixed. Otherwise larger particles and small particles will be loaded separately. If that happens, customer required sample size with proper grading would not be delivered. Service of experienced excavator and loader operators is highly important to minimize above drawbacks.

According to the respondent's opinion, this is not high critical factor, but critical and categorized under avoidable category (refer Table 4.10).

- **Lack of Proper Supervision and Management**

Supervision and management are highly important factor to maintain quality in any business. This is same for the aggregate mining industry. In quarrying process mainly sand stone and soil can get added to the rock production. Therefore close supervision is necessary to remove above waste materials. Before drilling and blasting, rock surface should be cleaned well. Also soil overburden and weathered rock layer should be removed properly. Moreover after blasting and before breakering sand stone should be removed. Sometimes sand stone can remain after the breakering process. Therefore at the time of loading it should be checked and removed properly. This means that all the process in exploitation stage should be well supervised.

At the crushing stage it is necessary to check sample size, grading and crusher settings properly. Otherwise customer required material with relevant sample size and grading cannot be supplied.

This was highlighted only cases A and B, but not highly mentioned in case C (Refer Table 4.10). According to respondent C2 *"they have 2 supervisors for quarry and another 2 supervisors for crushing and all of them are well experienced in quality controlling. Therefore they can maintain their quality in maximum level*". Hence "lack of supervision" is categorized as critical but avoidable factor under defects.

- **Raining**

According to respondent A1 *"small particles like dust (0-5mm size) settle down on the stock pile due to raining. Sometimes dust can be removed from the pile with rain water stream. In this type of situation grading of the sample can be completely changed".* This issue cannot be avoided due to the fact that the aggregate mining industry is an open environment business. However this was noticed in all three sites and therefore this is categorized as high critical factor affecting defects (Refer Table 4.10).

4.4.1.8 Underutilized People Waste

Minimum required and current number of employees in each stage to achieve present target production was recorded separately. Reasons were identified if numbers does not tally with each other and actions/ strategies to keep minimum requirement were identified. Employees' targets to achieve, employee controlling process, monitoring programme to compare performance against target, progress of work and business culture were mainly questioned by interviewers. Here some reasons for underutilized people were identified together with relevant control strategies. These reasons are illustrated in Figure 4.8 and the interviewers' responses show in Table 4.11.

Figure 4.8: Factors affecting Wastes on Underutilized People

Table 4.11: Respondents' responses on factors affecting waste under Underutilized People

Factors	Case A					Case B					Case C					
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	
Avoidable																
i) unsatisfied monthly salary and/or Lack of salary increment/ bones/ incentives	√	√	√	√	√	X	√	√	√	√	X	√	√	√	√	HC
ii)No facilitated & comfortable office space/ accommodations/ controlling rooms	√	√	√	√	√	X	X	√	√	√	X	√	X	√	√	HC
iii)lack of safety	X	√	X	√	√	X	√	√	√	√	X	√	√	√	√	HC
iv)bad appearance of site	√	√	√	X	√	X	X	√	X	X	X	√	X	√	√	C
v)Inappropriate gangue size	√	√	√	√	√	X	√	√	√	√	X	X	X	√	√	C
vi)No promotion scheme	X	X	X	X	X	X	X	X	X	X	√	√	√	X	X	NC
vii) Lack of admiration	X	X	X	X	X	X	X	X	√	X	X	X	√	X	X	NC
viii) Lack of proper supervision & management	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	NC
ix)Lack of employee skill development programme	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	NC
x)Lack of head office's concern on mining site	√	X	√	X	X	X	X	X	X	X	X	X	X	X	X	NC
xi)Lack of performance maintaining system	X	X	X	X	X	X	X	X	X	X	X	X	√	X	X	NC
Unavoidable	No					No					No					

- **Unsatisfied Monthly Salary and/ or Lack of Salary Increment/ Bones/ Incentive**

13 out of 15 respondents highlighted that they are unsatisfied with the salary (Refer Table 4.11). According to them, evens if they work hard cannot be satisfied about the monthly salary. Only two respondents in cases B and C are satisfied with their monthly remuneration, but both of them are in top management level of the organization.

According to respondent's opinion lack of salary increment/bonus/incentive leads to underutilization of people. Respondent C2 explained his experience regarding that *"even when the company made considerable high profits during past two years, they did not arrange any bonus or incentives. Also did not provide considerable salary increments and only provide entitle salary increment i.e. Rs.350/- per year. Preparation of monthly cost estimation reports for quarry and crushing site had been doing by him. But higher management of the company informed him to stop the preparation of above reports when he asked about salary increment and/or bones and/or incentive".*

Also respondent A1 stated that *"their company agreed to pay bonus for all if they cover the target before two months. Therefore all of them work hard and achieve relevant target, but still it is not arranged".*

According to the views of respondent this was identified as a high critical but avoidable factor affecting underutilized people.

- **No Facilitated and Comfortable Office Space /Accommodation/ Controlling Rooms**

Top and middle management of site A and C mentioned about their office premises. According to them their offices were not comfortable. Normally environment of the mining site is exposed to dust, noise and has to work in hard condition. Therefore it is clear that the office should be comfortable. Otherwise it leads to de-motivation of the office staff.

However, it was also inspected that even there isn't AC for offices in site A and C. But, office in case B is well facilitated and comfortable. Therefore all of them are happy about their office premises.

More than 50% respondents in all three cases mentioned that their accommodations are not in satisfactory level and all are having very low facility and low comforts (Table 4.11). Only 4 persons in case B and C did not mention about accommodation because they are coming to work from their homes.

Controlling room of the crusher plant is not in satisfactory level due to its old condition in case A and B specially. This room is not covered well and has no AC facility. Crushing area is normally exposed to dust and it is difficult to operate the crusher plant from this type of controlling room. Therefore interviewers highlighted this issue and it was proved by observation.

Hence these issues were identified as a high critical factor affecting underutilized people, but should be avoidable to keep positive mentality in all employees.

- **Lack of Safety**

Lack of safety is one of the serious issues identified in this research. According to the inspections and the respondent's opinions it was identified that both management and other staff do not given high attention about safety. It is necessary to give high concern about safety because of the high risk in aggregate mining industry. But it is clear that all companies do not provide all necessary personal protective equipment (PPE) for their employees and also they were not wearing even the provided equipment. According to respondent C4 *"company does not provide all PPE and only provide safety helmets".* Also respondent A4 stated that *"their company provide only safety helmets but does not like to wear it".*

It was identified that they don't much consider about the safety precautions that should be arranged before and after the rock blasting, explosive storage and handling, fire protection, and other environmental hazards i.e. dust, noise and waste. The main reason for above all is lack of awareness about safety. According to respondent A1 *"site safety should be improved in all areas. Initially awareness program should be conducted due to lack of knowledge about safety in every one. Also cannot be satisfied about the safety sign boards in the site .Also there are no fire extinguishers placed in the site and no any trained person about fire protection. Moreover their explosive magazine is not in a proper location. It is installed much closed to the office premises. Even the top management was informed about that but they do not expect to remove it to a safety location".*

Majority in all three cases highlighted about lack of safety in their sites and also inspected the practical situation. Therefore this was categorized as a high critical but avoidable factor affecting underutilized people.

- **Bad Appearance of Site**

Respondents 4, 1 and 3 in case A, B and C respectively were concerned about the bad appearance of the site (Refer Table 4.11). But others were not worried about the present appearance of the site. Majority of the case B were satisfied about their site appearance. It was inspected that their site is planned to some extent. Because they have separate location for machine parking, vehicle parking, machine and vehicle servicing, work shop and collecting of waste material. Maintenance and cleaning of all area of the site was done well. Although only respondent C3 was not satisfied about that condition and he expected more than the present situation.

However the appearances of other two sites were not in satisfactory level. It was observed that cleaning and maintenance of the sites were not done well and regular manner. Accommodation for workers in case A are situated within the site premises and it cause to add bad appearance to the site and also to the company. Present site layout also adds bad picture to the site. This condition is same for case B. Not having a proper waste material management system was specially identified in case B. Therefore waste materials like hydraulic and engine oil, vehicle and machine parts, empty cans, barrels and gallons could be seen everywhere of the site premises.

By considering all opinions and observations this was identified as a critical avoidable factor.

- **Inappropriate Gangue Size**

This was mainly identified as a factor affecting underutilized people in case A and B but only two respondents were highlighted in case C (Refer Table 4.11). Inappropriate gang size is cause to create negative mentality in members who are currently working in the gangue. Because they have to work harder or much time to reach their target.

Respondent A1 stated that *"currently there are only seven labourers for explosive charging and blasting, but minimum requirement is ten labourers. Therefore sometimes machine helpers are used for above, but both parties were de-motivated about this condition. Company was informed about this situation in several times, but they still have not answered"*. According to respondent B4 *"current gangue size for crusher is four but the minimum requirement is six. Even from them two are older than 60years"*. Hence inappropriate gangue size is another reason behind underutilized people.

- **No Promotion Scheme**

This was also identified only in the case C. Three respondents mentioned this as a reason for de-motivation for them (Refer Table 4.11). Respondent C3 explained about him as *"he engaged to the company as a crusher supervisor and have been working in same position for more than 22 years, but the company still did not give him a promotion"*. According to him and other two respondents this was same for all employees in the company. But this was identified as a non-critical factor because of the unique situation.

Figure 4.9 demonstrates cognitive map of all identified factors affecting wastes in Sri Lankan aggregate mining industry under main eight wastes. Further the map show the avoidable and unavoidable factors separately.

Figure 4.9

4.4.2 Lean Strategies to Minimize Waste

Lean strategies are discussed only for the highly critical and critical factors affecting wastes, which are under avoidable category. Strategies / actions proposed by the respondents to minimize each wastes are summarized in following Table 4.12. The proposed strategies were linked to relevant lean strategy by considering literature review and desk study.

Table 4.12: Proposed lean strategies to minimise wastes in Sri Lankan quarry industry

	Main Waste	Factors affecting waste	Proposed strategies	Lean Strategies
1	Over Production	1. Breakdown & maintenance of machines, plants & vehicles	1.Maintain check list for each machines, plants and vehicles and do relevant maintenance as necessarily	TPM
			2.Regular servicing	
			3.Service and maintenance are arrange at idle times	Work Standardization
			4. On time delivery of parts and tools	JIT
2	Waiting/ delay	1.Breakdown & maintenance of machines, plants & vehicles	1.Maintain check list for each machines, plants and vehicles and do relevant maintenance as necessarily	TPM
			2.Regular servicing	
			3.Service and maintenance are arrange at idle times	Work Standardization
			4. On time delivery of parts and tools	JIT
			5.Allocate the remaining machines by giving priority to critical works	Bottleneck analysis
3	Unnecessary Transportation	1.Double handling/ intermediate storage	1.Increase the space of stock piles in crusher plants	PDCA
			2.Changing of crusher layout	
4	Unnecessary Processing	1.Old plant, machine & vehicle	1.Maintain check list for well maintain with regular service	TPM
			2.Sell and buy new machine/plant/vehicle	PDCA
		2.Inappropriate gangue size	1.Hire required employees	Takt time
			2.Arrange workforce giving high concern to critical works	Bottleneck analysis
			3.Resource allocation to critical works	

5	Excess Inventories	Excess finished products (Blasted rock and crushed aggregates)	1.Produced only customer demand instead of projected demand	JIT, Kanban
6	Unnecessary Movement/ Motion	1.Unnecessary workers travel looking for parts, tools, helps	1.Maintain proper reporting system	5S
			2.Keep separate tool box for machine	
			3.Record book should be maintain	
			4.Maintain the tool store in well standard level	
			5.Conduct worker training programme	Kaizen
		2.Unnecessary machines travel within site for small repairs	1.Conduct operator training programme	Kaizen
7	Defects	1.Damage of Screen	1.Maintain check list	TPM, TQM
			2. If the sieve sets are old/wear, remove those and fix new.	TPM, Visual control, TQM, Poka-Yoke
			3.Close monitoring & supervision	TQM, Poka-Yoke
			4.Check the sample size randomly	TQM
			5. Sensors to identify damages in sieves and automatically stopped the process.	Jidoka (Autonomation)
		2.Sudden variation of crusher setting	1.Maintain check list (10hr, 20hr) to do relevant changes and maintenance as necessarily	TPM, TQM
			2.Remove the wear/damage parts when needed	TPM,Visual control, TQM, Poka-Yoke
			3.Close monitoring & supervision	TQM, Poka-Yoke
			4.Check the sample size randomly	TQM
			5.Sensors to identify sudden variation of crusher settings and automatically	Jidoka (Autonomation)

			stopped the process.	
		3.Uneven loading	1.recruit experience supervisors and/ or operators	TQM, Poka-Yoke
			2.Conduct supervisors and / or operators training programme	Kaizen
			3.Process under camera surveillance	Poka-Yoke
		4.Lack of proper supervision & management	1.Recruit experience supervisors	TQM, Poka-Yoke
			2.Process under camera surveillance	Poka-Yoke
8	Underutilized People	1.Unsatisfied monthly salary and/ or lack of proper salary increment/ bonus/ incentive	1.Introduce additional benefits (Plan medical schemes, welfare schemes, providing transportation, meal/food allowance, uniforms)	PDCA, Kaizen
			2.Performance based increments	PDCA
			3.Incentives for employees with lesser leaves	
			4.Introduce target base bonus	
		2.No facilitated & comfortable office space/ accommodations/ controlling rooms	1. Provide facilitated & comfortable office premises 2.Provide facilitated & comfortable accommodations /accommodation allowance 3. Provide comfortable controlling rooms	PDCA
		3.Lack of safety	1.Appoint a safety officer	TQM
			2.Provide necessary PPE	TQM
			3.Awareness programme should be conducted	Kaizen
			4.Conducting daily safety meeting	Daily huddle meeting
			5.Introduce rules and regulations	TQM
			6.Introduce punishment procedure	TQM
		4.bad appearance of site	1.Implementing 5S	5S
		5.Inapprpriate gangue size	1.Hire required employees	Takt time

4.4.2.1 Lean Strategies to Minimize Over Production Waste

Breakdown and maintenance of machines, plants and vehicles were identified as the high critical factor affecting waste under over production. Proposed strategies by respondents are shown in Table 4.12. According to them, preventive maintenance and early identification of the issues that cause breakdown is very important. Maintaining regular check list for each machine, plant and vehicle as necessarily with regular servicing is the proposed strategies for minimizing breakdowns.

Lubricating and cleaning frequently, inspecting and monitoring components for wear and damage are main concerns for large machinery maintenance. Maintaining of relevant lubricant level i.e. engine oil, transmission oil and hydraulic level and grease at all relevant points is important for preventive maintenance of the large mine machinery and plants. Keeping of a daily check list helps to check above important facts. This also helps to identify wear and damage parts early. This will help managers to get decision in right time to change those wear / damage parts before breakdown occur.

Respondents proposed to implement above methods for preventive maintenance of machines, plants and vehicles. The lean strategy relates to proactive and preventive maintenance to maximize the operational time of equipment is Total Productive Maintenance (TPM). TPM is a comprehensive productive-maintenance system covering the entire life of the equipment with the participation of all employees (Tsuchiya, 1992 cited McKone et al., 2001). That helps to equipment are maintained properly and eliminating of breakdown occurs (Kilparick, 2003).

Respondents also proposed to arrange service and maintenance only at idle times. Otherwise it will effect to the continuous flow of the entire process. Therefore proper schedule and instructions should be given to work group in an organized manner to arrange and to do the relevant service and maintenance. Work standardization is the suitable lean strategy for above and that should be implemented because it is advancing to work specifications and instructions in an organized manner (Lean tools and techniques, 2007).

It is important to prevent machines from being broken down so as to eliminate overproduction. One of the main reasons behind the breakdown of machines is the deterioration of parts and tools of the machine due to continuous operation. Therefore is important to have regular check up of machines and identify the parts and tools that need replacement. Those identified parts should be delivered and replaced on time to avoid breakdown. Since this is the main principle behind Just-In-Time (JIT) lean strategy implementing this would benefit to eliminate overproduction waste.

Finally above mentioned lean strategies i.e. TPM, Work standardization and JIT should be implemented together to minimise the overproduction waste in Sri Lankan quarry industry.

4.4.2.2 Lean Strategies to Minimize Waiting /Delay Waste

Breakdowns & maintenance of machines, plants & vehicles are identified as an avoidable factor affecting waste under waiting/ delay same as in over production. Therefore proposed strategies by respondents and relevant lean strategies were almost same as the overproduction (Refer Table 4.12).

Resource allocation to critical works is important at the time of machine / plant/ vehicle breakdown occur. According to respondent's opinions, remaining machines should be allocate by giving priority to critical works without enhancing waiting/ delay between any subsequent processing steps. Therefore it is better to identify the critical activities and correctly strengthen those without affecting to the entire process. Bottleneck analysis is the relevant lean strategy that helps to identify weakest link and improves the throughput by strengthening it (leanproduction.com, 2010-2013).

Therefore, bottleneck analysis can be identified additionally in the waiting/ delay other than the TPM, Work standardization and JIT lean strategies.

4.4.2.3 Lean Strategies to Minimize Unnecessary Transportation Waste

Double handling/ intermediate storage is one of the highly critical factor affecting waste identified under unnecessary transportation. Low space of the crusher stock piles is the main reason for double handling identified in Sri Lankan quarry industry. According to respondents, stock piling space of the existing crushing plant should be increased by changing the crusher layout (refer Table 4.12). Partially or completely changing the crusher layout will not be a simple process. It will be a long time costly process. Therefore that should be planned in a cost effective and technically feasible manner prior to implementing stage.

PDCA lean strategy can be used to change the crusher layout efficiently to facilitate more stock piling space to the production. Initially, the expected crusher layout can be designed with relevant design changes to meet expectation. Then the planed layout can be implemented by doing relevant layout changes partially or fully. After the implementation stage, organizations can check weather their expected results are met. If any complications arise, those can be solved by re executing the PDCA cycle.

4.4.2.4 Lean Strategies to Minimize Unnecessary Processing Waste

Old plant, machine & vehicle were identified as a factor affecting waste under unnecessary processing. It is clear that it is difficult to operate in its' normal efficiency when those are old. Therefore it is better to have proper maintenance with regular service. Otherwise their efficiency will be further reduced than the current. It causes to increase the unnecessary processing waste. Respondents proposed to maintain check list for proper maintenance with regular service similar to over production and waiting/delay (refer Table 4.12). Therefore TPM can be used as a lean strategy as discussed before.

Another proposed strategy to eliminate above factor affecting waste is to sell old machines/plants/vehicles and buy new ones (refer Table.4.12). Proper planning should be followed in both buying and selling. When selling old machines the company should inquire about market prices and relevant rules and regulations that have to be followed. Also when buying new machines the company should consider about latest technology, production capacity needed and the cost. Therefore it is best to adopt PDCA lean strategy to eliminate the factor affecting waste.

Inappropriate gangue size is another factor identified under unnecessary processing. Hiring of required employees was the proposed strategy by respondents (refer Table 4.12). In lean way Takt time technique can be used to determine the optimal staff required i.e. the correct number of staff to be worked at a specific Takt time, no more or less (isixsigma 2013 cited Mwacharo,2013).

According to the respondents when the gangue sizes are less, arrangement of workforce by giving high concern to critical works is important (refer Table 4.12). If the management failed to identify critical activities and allocation of optimum resource to critical works, it will affect to further increase the unnecessary processing waste. Bottleneck analysis is the relevant lean strategy that helps to identify the critical activities and correctly strengthen those without affecting the entire process.

4.4.2.5 Lean Strategies to Minimize Excess Inventories Waste

Inventory can mainly be categorized into two types; raw material/machine inventory and finished product inventory. With respect to the sample quarries there were no excess raw material/machine inventory identified. Please refer to Annex C

However there was an excess inventory of finished products in the means of blasted rock and crushed aggregates. This waste is really the overproduction waste. However in addition to the strategies identified under overproduction, another proposed strategy to minimize excess inventory is to produce equal to the customer demand instead of producing to the projected demand. Since the principle behind the kanban and JIT are to produce what is needed, at the time needed in the required amount these lean strategies can be applied to eliminate excess inventory.

Sri Lankan aggregate market can be identified as a perfect competition. There are many types of customers as well as suppliers. Due to the unpredictable nature of construction material demand and due to the varying number of domestic customers, it is quite difficult to have an exact figure of required demand. For example even if the construction projects give an exact value, it is impossible to imagine the exact the number of domestic customers that would appear. Therefore with respect to the existing market structure, to maintain a good customer satisfaction, excess inventory is needed.

4.4.2.6 Lean Strategies to Minimize Unnecessary Movement/ Motion waste

One of the factor affecting wastes that come under this waste category is workers travelling unnecessarily looking for parts, tools, helps. Strategies proposed to eliminate this are maintaining proper reporting system, keeping separate tool box for machines, maintaining record properly and maintaining the tool store in well standard level (refer Table 4.12). Proper reporting system is not being maintaining for machine breakdown and store maintenance. No recording system is keeping when the parts and tools are issued to the work teams. Workers/ supervisors are also not exercised to keep record books. If they practiced to use record books they can note down the nature of breakdown/ maintenance and required tools and parts at once. Therefore when machine/ plant/ vehicle breakdown or maintenance occurs, workers have to travel unnecessarily more than once looking for parts, tools and helps for same work to same place. Not maintaining the tool store in an organized and systematic level leads to unnecessary movement of workers. Therefore to minimise the unnecessary movement waste, it is necessary to turn the above mentioned disorganised work place in to an organised, systematic one. Applicable lean strategy for that is 5S (Bicheno & Holweg 2009 cited Mwacharo,2013). This technique is usually well accepted among employees and commonly used as entry point for lean thinking (Andi et.al, 2009).

Lack of knowledge and experience regarding machine breakdown and maintenance leads to the unnecessary movement of workers. Therefore it is proposed to conduct worker training programs (Table.4.12). To do this effectively Kaizen lean strategy should be adopted. In Kaizen worker training programs are conducted such that they are continuously improved. For example workers can be grouped according to their knowledge and then conduct training programs according to their level. These training programs should be organized in a continuous manner increasing its standard. Workers should be always armed with new knowledge.

Unnecessary machines travel within site for small repairs is identified as another factor affecting waste under unnecessary movement/ motion. Normally when small breakdowns take place at the site i.e. breaking of a tooth pin of a excavator bucket, pull out or breaking of main pins in arm/boom/bucket/breaker unit and breaking or pull out of pin lock, interruption of the electrical system; machine operators can make those within the site premises without travelling to the workshop, if they have enough knowledge and experience. Therefore conduction of operator training programme is valuable to minimized above waste (refer Table 4.12). Kaizen lean strategy can be implemented to continuously improve the training programme as explained above.

4.4.2.7 Lean Strategies to Minimize Defects Waste

Proposed strategies to the factor affecting damage of screen that comes under defects waste category are maintaining check list, close monitoring & supervision, if the sieve sets are old/wear, removing those, fixing new and checking the sample size randomly and fixing sensors to stop the process before a defect occurs. (Refer Table 4.12).

It is important to maintain daily/ hourly (e.g: 10hr, 20hr, etc.) base check list for all valuable aspects of the crusher plant including screening unit. It helps to identify wear/ damage parts early to replace new parts and to do the relevant service and maintenance properly in time. If the currently using screen sets are old / wear, possibility to damage is high and therefore remove those and fix new sieve sets immediately. These proposed strategies come under preventive maintenance of crusher plants and that can be achieved by implementing lean strategy of TPM and poka-yoke. Also the lean strategy visual controls can be used to identify parts which need replacement by lights or colour card system.

Close monitoring and supervision during whole operating period is important because damage of screen set can be happen in any time even if those are maintained well due to the hard-wearing condition of the process. Recruiting supervisors for close monitoring comes under increased employee involvement and teamwork of TQM (Ross, 1993). By close supervision sieves probable for damage can be easily identified and replaced before damage occurs which comes under Poka-Yoke strategy. Checking the sample size randomly is also important to reduce the rework and to keep the customer satisfaction by supplying demanded sample sizes. This proposed strategy comes under constant measurement of results in TQM (Ross, 1993). Since TQM mainly focuses on preventing of occurring errors it helps to improve the quality. Primary objective of all proposed strategies by respondents are preventing of occurring of errors (Black & Porter, 1996). Therefore above all strategies can be achieved by implementing TQM. Another proposed strategy is to install sensors in the machines to detect the wearing of sieves. This strategy can be identified as the Jidoka strategy in lean. This principle behind this is 'automation behind human touch', which means that machine is automated such that it can stop by itself before a defect occurs.

Sudden variation of crusher settings is another factor affecting waste that can occur. Here it is especially important to maintain primary and secondary crusher settings correctly. Both hydraulic and mechanical systems are used to adjust above crusher settings. Reasons for always changing of the crusher settings are; wear of mechanical parts, changing hydraulic pressure and old condition of the plant. Maintaining check list for doing relevant changes and maintenance as necessarily, close monitoring & supervision, removing the wear parts when needed and checking the sample size randomly are strategies proposed to eliminate this factor affecting waste (refer Table 4.12). As mentioned above by adopting TQM, TPM and Poka-Yoke lean strategies all these can be implemented successfully. In addition to identify wear parts and to replace them timely, visual control strategy can be adopted. Similar to the screen damage, to identify the variations in crusher settings and stop the process before defects occur Jidoka strategy can be implemented.

For uneven loading factor three strategies are proposed. One is recruitment of experienced supervisors and/ or operators because they tend to make lesser mistakes than inexperienced employees. The theory behind this is to prevent occurring of errors hence comes under both TQM lean strategy and Poka-Yoke. Another proposed strategy is conducting supervisors and / or operators training programs. As mentioned in earlier waste categories this comes under Kaizen lean strategy. Also when the process under camera surveillance, employees tends to be more responsible about their work hence lesser errors are made. This error proof strategy can be identified under Poka-yoke.

Many suggest that the factor lack of proper supervision and management occur mainly due to inexperience of supervisors. Hence proposed strategy is to recruit experienced supervisors. Also the process can be maintained under camera surveillance. And as explained earlier these come under TQM and Poka-Yoke lean strategies.

4.4.2.8 Lean Strategies to Minimize Underutilized People Waste

Unsatisfied monthly salary and/or Lack of proper salary increment/ bones/ incentivesis one of the factor affecting wastes that occur under main waste of underutilization of people. However it is not always practical to increase salary till employee get satisfied. But a good strategy is to give additional benefits to employees (refer Table 4.12). If think in a lean way PDCA strategy can be used to provide additional benefits to employees. The company can plan what benefits they should give to their employees i.e. Plan medical schemes, welfare schemes, providing transportation, meal/food allowance, uniforms, how it should be given and how much should be given. Then after implementing the plan the company can check whether their employees are satisfied with what they are given. And if any complications arise, those can re execute the PDCA cycle. Also company can implement Kaizen strategy by getting ideas from their own employees or peer companies regarding giving additional benefits to employees. And by implementing practical ideas and checking their affectivity can continuously improve employee satisfaction.

Also lack of salary increment/ bones/ incentives can be eliminated by implementing strategies like performance based increments, giving incentives for employees with less absenteeism and introducing target base bonus (Table.4.12). But to do this in a lean way, best is to go with PDCA strategy.

Similarly the factor of no facilitated and comfortable office space/ accommodations/ controlling rooms can only be eliminated by providing it as required. However if this is done in a haphazard way, required objectives may not be achieved. It should be done after properly identifying required comforts and facilities, means of providing those and means of maintain. Also after providing these should check whether required aims are achieved. Hence to do this lean strategy PDCA should be adopted.

Mining industry is one of the high risk and dangerous industries in the world. Therefore much attention should be given to the field of safety. But in Sri Lankan context only concern is about making high profits by producing more aggregates with low cost. The organizations do not worry about the workers safety as well as the environment and do not like to allocate funds to improve site safety and environment safety. Therefore lack of safety was identified as a factor affecting waste under underutilization of people. Numbers of strategies are listed in Table 4.12 to avoid the factor lack of safety. First and foremost a separate safety officer should be appointed and then PPE should be provided. Because safety unquestionably affects to quality of product and process, in lean these are discussed under TQM strategy. The other proposed strategy which is conducting of awareness programs comes under Kaizen in lean. It is because employees should be continuously kept well aware about safety issues in mining industry and should be well up to date regarding avoiding/reacting to these issues. Conducting of daily safety meeting includes reminding employees about importance of adhering to safety rules and discussing about a safety issue that arise while working in about 10 to 15 minutes time. In lean this is similar to conducting of daily huddle meetings. The other proposed strategies are introducing rules and regulations and punishment procedures. Through the lean strategy TQM these proposed strategies can be fulfilled. The aim of introducing rules and punishments is to prevent occurring of errors which is the core of TQM.

To eliminate the factor of bad appearance of site, it should be properly cleaned and should be kept in an orderly manner. Machines and equipment should have a proper place and wastes should be removed properly. All these can be achieved by implementing the well known basic lean principle the 5S.

Also as mentioned above for the factor affecting waste of lack of gangue size, required number of employees should be hired and to do this in lean way Takt time strategy should be employed.

4.4 Framework to Minimize Waste in Sri Lankan Quarry Industry

Figure 4.10 demonstrates the final framework to minimize waste in Sri Lankan quarry industry by applying of lean strategies. Left side of the framework shows the main eight wastes/ non-value adding activities identified from the literature review. The middle column shows the avoidable factors affecting wastes identified through the case study under above main wastes. Suitable lean strategies to minimize factors affecting wastes are showing in right side of the framework.

It is very difficult to find a systematically well-developed quarry although there is a high demand for aggregate product in Sri Lanka. So many factors affecting wastes were identified in this research and this significantly affect to the efficiency of quarry projects as well as construction projects that depend on those quarry sites. Therefore it is time to implement lean strategies to minimize wastes in quarry industry.

All top and middle management of the aggregate mining industry can use this framework. If any aggregate mining industry has any factors that would ultimately arise main waste, they can implement relevant lean strategies illustrated in the framework to minimize wastes and optimize the performance of quarry industry.

Figure 4.10

4.5 Summary

This chapter is explained descriptive way on research findings and analysis of data. Initially Cross case analysis was carried out to identify highly critical, critical and non-critical factors affecting wastes under main eight wastes. Then the cognitive map was created including all identified factors affecting wastes in Sri Lankan aggregate mining industry by separating avoidable and unavoidable factors. Then Lean strategies are discussed only for the highly critical and critical factors affecting wastes, which are under avoidable category. Here, proposed strategies were linked to relevant lean strategy by considering literature review and desk study. Finally, the framework to minimize non-value adding activities (wastes) in quarry industry was prepared as the ultimate goal of the study.

CHAPTER 05

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter provides conclusions of the research study. The chapter further presents contribution to the industry and further research.

5.2 Conclusions

Aggregates/ metals obtained by quarrying are one of the most commonly available mineral resources in anywhere in the country and is a basic raw material used by the construction industry (Herath, 2010). Due to the rapid increase of construction industry, the demand for rock is also increasing which in turn increase the number of metal quarries in the country. It is very difficult to find a systematically well-developed quarry although there is a high demand for aggregate products in Sri Lanka. Therefore, there is a need to enhance process performance in industrial quarry projects. Thus there is a need to implement concept such as lean philosophy in order to eliminate or minimize non-value adding activities and to optimize quarry operation.

Lean is a performance-based process and focus on the elimination of waste or non-value added steps within the entire industry or organization (McGivern & Stiber, 2014). Lean management also helps to increase the quality of products, reduce the operation time and decrease the production cost (Rylander,2013).

Lean principles have been applied in almost all type of manufacturing industries over the past 30 years since its origin from the Toyota production system and dramatically penetrate to the other industries like construction and mining (Andi et al., 2009). But in Sri Lanka, lean concept is not widely used yet except in few garment factories (Danasooriya, 2011). Therefore, this concept is also not familiar to the Sri Lankan mining industry and there is a lack of research findings on the applicability of lean principle to minimize waste in Sri Lankan mining Industry. Therefore, it is time to investigate the benefits of implementing lean principle to the quarry industry. This research intends to perform the above mentioned investigation along with the in-depth analysis of quarry operation and it will help to add the term of lean concept to the Sri Lankan mining industry.

The aim of this research was to identify lean strategies to minimize waste in Sri Lankan quarry industry. In order to achieve this aim four objectives were formulated. First objective was achieved successfully through the comprehensive literature review and other three objectives were achieved through the empirical study which was conducted by chapter 04.

First objective was to review the lean concept and its application, mining industry and processes in quarry industry, the application of lean concept in mining industry and main industrial wastes/ non-value adding activities. This objective was successfully achieved through a comprehensive literature survey carried out by referring to books, journals articles, published research papers, unpublished dissertations and internet sources. End of the literature review the conceptual model for the study was developed as a main outcome of the literature survey (refer Figure 2.20).

The empirical study was carried out to achieve other three objectives. The second objective was to investigate the factors affecting wastes under main wastes in different processes in quarry industry. This was achieved through multiple case study research. Three industrial quarry projects which are under IML-A category (large scale) were selected under the multiple case study design to suit time constraints and convenience. Data collection for the case study was based on semi structured manner according to open ended questions to enhance the richness of the information collected (refer Annex A). The interviews were conducted with five participants for each case and altogether, 15 interviews were conducted. Cross case analysis was carried out separately under main eight wastes identified in the literature survey. Factors affecting wastes identified under each main waste category in the case study were categorised as avoidable and unavoidable (refer Annex C). Identified factors were further categorized as highly critical, critical and not critical by considering respondents' responses (refer Annex C and Table 4.3). Finally, cognitive map was developed for all identified factors affecting wastes in Sri Lankan aggregate mining industry under main eight wastes, i.e.: (1)Over Production (2) Waiting / Delay (3) Unnecessary Transportation (4) Unnecessary Processing (5) Excess Inventories (6) Unnecessary Movement/ Motion (7) Defects (8) Underutilized People (refer Figure 4.9).

Breakdown and maintenance of machines, plants and vehicles was identified as a high critical avoidable factor affecting wastes for both over production and waiting/ delay. Double handling/ intermediate storage, Old plant, machine & vehicle, Excess finished products, Workers travelling unnecessarily looking for parts, tools, helps, Damage of Screen, Unsatisfied monthly salary and/ or Lack of salary increments/ bones/ incentives were some identified avoidable factors affecting wastes under Unnecessary Transportation, Unnecessary Processing, Excess Inventories, Unnecessary Movement/ Motion. Defects, Underutilized People respectively (refer Table 4.3 & Figure 4.9).

Unavoidable factors were only identified under four main wastes i.e. over production, waiting/ delay, unnecessary processing and defects. Bad weather condition, safety issue in the blasting time, bore holes fill with water, raining were some factors respectively.

Lean strategies were discussed only for the highly critical and critical factors affecting wastes, which are under avoidable category. The proposed strategies by respondents were linked to relevant lean strategy by considering literature review and desk study. Accordingly 14 lean strategies i.e. TPM, Work Standardization, JIT, Bottleneck analysis, PDCA, Takt time, Kanban, 5S, Kaizen, TQM, Visual Control, Poka-Yoke, Jidoka, Daily huddle meeting were identified to minimize wastes in Sri Lankan quarry industry by this study (refer Table 4.12).

Finally, initially developed conceptual model (refer Figure 2.20) was modified by adding avoidable high critical and critical factors affecting wastes and relevant lean strategies. This framework to minimize waste (non-value adding activities) in Sri Lankan quarry industry gives the final outcome of the research (refer Figure 4.10).

All top and middle management of the aggregate mining industry can use this framework. If any aggregate mining industry has any factors that would ultimately arise main waste, they can implement relevant lean strategies illustrated in the framework to minimize wastes and optimize the performance of quarry industry.

5.3 Recommendations to the Mining Industry

The lean concept is not familiar to the Sri Lankan mining industry and there is a lack of research findings on the applicability of lean principle to minimize waste in Sri Lankan mining Industry. This research intends to perform the above mentioned investigation along with the in-depth analysis of quarry operation and it helps to add the term of lean concept to the Sri Lankan mining industry. This was the main contribution to the industry.

Purpose of this study is to identify lean strategise to minimize waste in Sri Lankan quarry industry. Therefore, the research mainly focuses to find out the factors affecting wastes under main eight industrial wastes, lean strategies to minimize wastes and introduce a new framework to minimize wastes in quarry industry. These findings are other contributors to the industry and based on above findings following recommendations can be made.

- To use the proposed framework to identify the relevant main industrial wastes (NVAA) and applicable lean strategies, after identify the affecting factors.
- To implement the proposed framework as necessarily in quarry industry to optimize the performance by minimizing wastes.
- To use for other mining industries with some minor modifications.

5.4 Recommendations for Further Research

Following ideas can be highlighted for further research by considering this research.

1. Apply the proposed framework for wider cases to evaluate the validity and generalisability of the framework.
2. Extend the study to identify lean strategies to minimize wastes in all 6 stages, Prospecting, Exploration, Development, Exploitation, Processing and Marketing in Sri Lankan aggregate mining industry.
3. Extend the study to identify lean strategies to minimize wastes in underground mining processes in Sri Lankan mining industry.

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ANNEX A: CASE STUDY INTERVIEW GUIDELINE

Department of Building Economics,

University of Moratuwa,

Katubedda.

…………………………

…………………………

…………………………

Dear Sir/ Madam,

Re: Dissertation – MSc in Project Management, University of Moratuwa.

I am Lakshitha Dinesh Jayalath, following an MSc in Project Management degree programme of the Department of Building Economics at University of Moratuwa. I am conducting a research under the supervision of Dr. YasangikaSandanayaka on "Identifying lean strategies to minimize wastes in Sri Lankan quarry industry". This concept is not familiar to the Sri Lankan mining industry and there is a lack of research findings on applicability of lean principle to minimize wastes in Sri Lankan mining industry.

There is a high demand for aggregate products in Sri Lanka, but it is very difficult to find a systematically well-developed quarry site. Therefore it is time to investigate the benefits of implementing lean principles to the quarry industry. This research is performed along with the in-depth analysis of quarry operations by doing selected case studies. Therefore, I seek information from your project site. I would be grateful if you could kindly allow me to obtain information from your project under the attached guidelines. The actual names of the projects and the interviewees will not be revealed in this report or any other document relating to this study. The information provided will be treated with strict confidence.

Thank You.

Jayalath S.D.L.D.,
MSc Student
Department of Building Economics,
University of Moratuwa,
E-mail: sdldjayalath@gmail.com
Mob: 077-2206948

INTERVIEW GUIDELINE

PART 1

Background Information

Name of the Organization/Project (Optional): ………………………………………

Name of the Respondent (Optional): …………………………………………………

Designation of the Respondent: ……………………………………………………

Years of Experience: ……………………………………………………………..

PART 2

General Information of Industry

2.1. Please give general information of the site based on the guide given below.

a) Name of the developer (Optional)
b) Date of Commencement
c) Location of the site
d) Objective of the project
e) Production categories
f) Total number of employees

2.2. Please give brief introduction of the Exploitation / Quarrying stage based on the guide given below.

a) Licence category of the quarry
b) Total area of the quarry
c) Permitted area for the quarrying activities
d) Total estimated rock volume of this permitted area
e) Applied mining method
f) Permitted blasting parameters
g) Number of employees

h) Present demand and supply of each category.

Production category	Present Demand	Currently achieving Qty (Present Supply)

i) Briefly introduce
- Drilling process
- Blasting process
- Mucking, scaling and breaking processes
- Loading process
- Transportation process

2.3. Please give brief introduction of the Processing / Crushing stage

a) Machineries using for crushing process with their capacities

b) Number of employees

c) Demand and supply of each category.

Production category	Present Demand	Currently achieving Qty (Present Supply)

PART 3

Identification of wastes in exploitationand processing stages in quarry projects

3.1. Over production wastes

a) Is there any excess quarry production? Yes ☐ No ☐

b) If "Yes"

i) How much and which categories?

ii) Why this excess production is keeping?

iii) What are the actions (strategies) taken to reduce?

c) If “No”

i) Is it same as demand or less?

ii) Have you face any problem due to none having excess production?

d) Is there any excess crusher production? Yes ☐ No ☐

e) If “yes”

i) How much and which categories?

ii) Why this excess production is keeping?

iii) What are the actions (strategies) taken to reduce?

f) If “No”

i) Is it same as demand or less?

ii) Have you face any problem due to none having excess production?

3.2. Waiting/ Delay

a) Please answer to the following

	Are there any delays due to	**Yes/ No**	**If “Yes”, Details**	**Proposed actions/ suggestions/strategies to reduce delays**	**If No, what are the strategies used to reduce delays?**
1	Machine and / or plant breakdowns and / or maintenance?				
2	Waiting for materials?				
3	Waiting for equipment/tools?				
4	Waiting for information / instructions?				
5	Present site layout?				
6	Any other reasons?				

b) Are there any delays between subsequent processing steps / is there any waiting time for the next processing step?

	Subsequent Processing Steps	**Yes/ No**	**If "Yes", Details**	**Actions/ suggestions/strategies to reduce delays**	**If No, what are the strategies used to reduce delays?**
1	Drilling – Charging				
2	Charging-Blasting				
3	Blasting-Mucking, Scaling & Breaking				
4	Breaking – Loading				
5	Loading – Transporting				
6	Transporting – Processing				

c) What is the current production cycle time?

d) What are the actions (strategies) taken to reduce cycle time?

3.3. Unnecessary Transportation

a) Briefly explain about internal and external transportation use in the site.

Use Methods	**Approximate distance**	**Is there any possibility of reducing distance?**	**If there is a possibility, how to reduce?**
Internal transportation			
External transportation			

b) Are there any delays in above transportation methods?

c) If there is a delay what are the reasons?

d) Propose actions/ strategies/ suggestions to reduce delays?

e) Is there any intermediate storages/ double handling occasions?

f) If yes, what are the reasons for intermediate storages/ double handling?

g) Is there any possibility of reducing intermediate storages/ double handling?

h) If there is a possibility, How to reduce?

3.4. Unnecessary processing

a) What is the average timerequired and currently taking time for each stage?

Stage	**Qty**	**Average time required**	**Actual time**
Drilling			
Charging & Blasting			
Mucking, Scaling &Braking			
Loading			
Transporting			
Processing/ Crushing			

b) If above times do not tally with each other, what is the reason for that?

c) What kind of strategies can be taken to tally these times?

d) If above times are tally with each other, what kind of strategies are already used?

e) Are there any inappropriate production/ processing steps in this site?

f) If yes, do you have taken any actions (strategies) to eliminate those?

3.5. Excess Inventories

a) What is the minimum required and currently use of inventories to achieve present demand?

	Item	**Minimum requirement**	**Current availability**
Machineries			
1.	Rock drilling machine/ Track drilling machine		
2.	Air Compressor		
3.	Excavator		
4.	Breaker		
5.	Loader		

6.	Exploder		
7.	Dump trucks		
8.	Double cab/ Jeep		
9.	Vibrating feeder		
10.	Jaw crusher		
11.	Cone crusher/ Impact crusher		
12.	Vibrating screen		
13.	Generator		
14.	Water bowser		
15.	Any other		
Material			
1.	Drill bits		
2.	Drill rods		
3.	Ammonium Nitrate		
4.	Dynamite/ Water gel		
5.	Electric/ Plane detonators		
6.	Fuel		
7.	Grease		
8.	Hydraulic Oil		
9.	Engine oil		
10.	Any other		

b) If above numbers do not tally with each other, what is the reason for that?

c) Do you have any actions/ strategies to keep minimum requirement?

3.6. Unnecessary Movement/Motion

	Exploitation / Quarrying stage		**Processing / Crushing stage**	
	Machinery Movements	**Human Motions**	**Machinery Movements**	**Human Motions**
Types				
Are there any unnecessary……….? (Eg: Turning, Lifting, Reaching, Traveling/ looking for parts, tools, helps, etc.)	Yes / No	Yes / No	Yes / No	Yes / No

If yes, What are those?				
What are the reasons for these movements/ motions?				
Is there any possibility to reduce these movements/ motions?	Yes / No	Yes / No	Yes / No	Yes / No
If yes, what are the strategies taken to reduce?				

3.7. Defects

a) Which production categories are demanded by the customers?
b) What are the quality requirements expected by the customers in each category? Sieve analysis, Flakiness Index, Loss Angelies Abrasion Value (LAAV), Aggregate Impact Value (AIV)
c) What actions are currently taking to maintainrelevant qualities?
d) How to eliminate the adding of foreign materials / impurities to the production?
e) Is there any possibility to arise quality issues in production?
f) If yes, what are those?and what actions (strategies) can be taken to eliminate these issues?
g) Is there any possibility to reject the productions due to poor quality?
h) Has your organization faced to that type of occasions?
i) If your organization would have to face these types of occasions, how to handle rejected productions?
j) Is there any scrap production in your site?
k) If yes, do you have any suggestions (strategies) to minimize this scrap production?
l) Do you think that any repairs of machines and/ or plant is a solution for maintain production quality?

3.8. Underutilized people

a) What are the minimum required and currently using employees for each stage to achieve present demand?

Stage	**Minimum requirement**	**Actual availability**
Drilling		
Charging & Blasting		
Mucking, Scaling & Braking		
Loading		
Transporting		
Processing/ Crushing		

b) If above numbers do not tally with each other, what is the reason for that?
c) Do you have any actions/ strategies to keep minimum requirement?
d) Has each employee got target to achieve? Please explain those?
e) Do you have any employee controlling process to reach their targets?
f) Do you have any monitoring programme to compare performance against targets?
g) How are their performances?
h) If they cannot achieve their targets, what are the reasons for that? What type of corrective actions can be taken?
i) If they can achieve their targets, which methods can be implemented to increase the progress of work?
j) Does this business culture de-motivate the employees?
k) If yes, please explain the situation?
l) As you believe, is this project use their employee creativity, physical skills and abilities in success to reach to the project goal?
m) Please explain those situations?

ANNEX B: SAMPLE CASE STUDY INTERVIEW TRANSCRIPT

PART 1

<u>Background Information</u>

Name of the Organization/Project (Optional): Quarry and crushing plant project (Case A)

Name of the Respondent (Optional): Respondent A1

Designation of the Respondent: Site Manager

Years of Experience: 08 years

PART 2

<u>General Information of Industry</u>

2.1. Please give general information of the site based on the guide given below.

g) Name of the developer (Optional): *Case A*

h) Date of Commencement: *2003*

i) Location of the site: *Kaluthara District*

j) Objective of the project:

To provide aggregates and boulders for building and road construction projects in surrounding areas.

k) Production categories:

ABC (0-40mm), Asphalt aggregates (0-4mm: Dust, 4-8mm:Chip, 8-16mm:1/2inch, 16-20mm:3/4inch), Concrete aggregate (12-20mm), C1 (0-500mm), Boulders (1/2-2 ton).

l) Total number of employees: *45 nos.*

2.2. Please give brief introduction of the Exploitation / Quarrying stage based on the guide given below.

j) Licence category of the quarry: *IML - A*

k) Total area of the quarry: *4.5 Hectares*

l) Permitted area for the quarrying activities: *1 Hectares*

m) Total estimated rock volume of this permitted area:

Remaining rock volume is about 1,500,000 ton.

n) Applied mining method:

Multi bore–hole blasting method using compressed air driven hand drills and electric detonators.

o) Permitted blasting parameters:

This is different with the production category of the quarry. If we do a blast for feed to the crusher plant to take aggregate normally we keep 1.5m x 1.3m spacing and burden. Explosive is charged by keeping a powder factor 2.5-3 kg/m3. Hole depth is 4m and diameter is 40mm. 20- 30 charged bore holes fire at same time. Also in these days we have to supply 1/2 -2 ton size boulders to railway project. For that we keep 1.5m x 1.5m spacing and burden. Powder factor keep in below 2kg/m3.

p) Number of employees: *28 nos.*

q) Present demand and supply of each category.

Production category	**Present Demand**	**Currently achieving Qty (Present Supply)**
Quarry run for crusher	*1000 ton/ day (8 hours)*	*1200 ton/day (8 hours)*
Boulders (1/2-2 ton)	*Total qty 25,000 ton*	*Remain only 3,000 ton*

r) Briefly introduce

- Drilling process

  Drilling is done by a subcontractor. They use 3 air compressors, 3 jack hammers and 6 drillers. Normal drilling capacity is 250ft/hr by one jack hammer.

- Blasting process

  Use ANFO and water gel explosives. Daily around 60 holes are blasted but not fire together. Charge as 2-3 blast and fire as it is.

- Mucking, scaling and breaking processes

  For mucking and scaling we use excavators. Brakering is done by hydraulic breakers attached to excavators.

- Loading process

Blasted rock load to the dump trucks by using excavators and crusher productions is load to the dump truck by using both excavator and wheel loader.

- Transportation process

  Loaded dump trucks are travel from quarry to crusher plant to feed blasted rocks. It has a distance of about 100m. Aggregate production is sent from crusher to relevant projects. The traveling distance varies with the project. Some time it takes around 50kms.

2.3. Please give brief introduction of the Processing / Crushing stage

d) Machineries using for crushing process with their capacities

Jaw Crusher (1 nos.) – 150 ton/hr

Cone crusher (2 nos.) – 150ton/hr

Primary Screen (1nos.) – size 8feet x 12feet

Secondary Screen (1nos.)- Size 12feet x 16feet

e) Number of employees: *17 nos.*

f) Demand and supply of each category:

Demand is depend with project to project and difficult to predict it. Anyway demanded quantity by the projects we need to supply. So we try to achieve more than demanded in every month.

PART 3

Identification of wastes in exploitation and processing stages in quarry projects

3.1. Over production wastes

g) Is there any excess quarry production? *Yes*

h) If "Yes"

i) How much and which categories?

Rock material is a critical one of the supply chain of the construction project and there is a machine fleet demanding continues material supply for the project. Therefore we shouldhave enough quantity of aggregate materials at any time as the project expect. Daily demand of any construction project can vary and is not same in every day. Therefore excess quarry production should *be maintained. But it is difficult to give an exact figure for quantity that should be maintained because it depends on time. But we target to achieve in any category around double production of the average demand is needed.*

ii) Why this excess production is keeping?

Quarry operations are immensely affected by weather conditions. For example blasting operations cannot be carried out during rainy time. Therefore excess production helps to maintain the demand without a break. Also aggregate demand is not a constant quantity. It greatly depends on the type of construction being carried out. Hence excess inventory is essential to match the demand. On the other hand even though the machines are maintained at the required level, breakdowns are unavoidable. In some days all excavators in site have been broken down. Therefore to minimize the effect to supply due to machine breakdown excess production is necessary.

iii) What are the actions (strategies) taken to reduce?

No strategies are required because excess amount is necessary.

i) Is there any excess crusher production? *Yes*

j) If "Yes"

i) How much and which categories?

Same in quarry here also try to achieve at least double production of the demand in any category.

ii) Why this excess production is keeping?

As explain before to face bad weather, uneven fluctuation of the daily demand and specially breakdown of machines, plants and vehicles. As an example, our Jaw unit of the crusher plant had been broken down for 3 months, but still has not repaired, because parts are not available in the country. Therefore we used our excess crusher production for one week until the mobile crusher was delivered to the site.

iii) What are the actions (strategies) taken to reduce?

No need to take any strategies to reduce.

3.2. Waiting/ Delay

e) Please answer to the following

	Are there any delays due to	**Yes/ No**	**If "Yes", Details**	**Proposed actions/ suggestions/strategies to reduce delays**	**If No, what are the strategies used to reduce delays?**
1	Machine and / or plant breakdowns and / or maintenance?	*Yes*	*Jaw breakdown of the crusher caused crushing delay.*	*Use company owned mobile jaw for crusher.* *Analyze critical steps of the process, and allocate the crushers suitably.* *Proper machine maintenance after operating hours.*	
2	Waiting for materials?	*No*			*Use material records it could purchased when reach a critical value*
3	Waiting for equipment/tools?	*No*			*Because company service team maintains equipments properly*
4	Waiting for information / instructions?	*No*			*Employee at any level can contact the required person directly hence can get*

					the correct information
5	Present site layout?	*No*			Identified site layout issues already rectified.
6	Bad weather	*Yes*	All activities in the process have to be stopped	Cannot take any action	

f) Are there any delays between subsequent processing steps / is there any waiting time for the next processing step?

	Subsequent Processing Steps	**Yes/ No**	**If "Yes", Details**	**Actions/ suggestions/strategies to reduce delays**	**If No, what are the strategies used to reduce delays?**
1	Drilling – Charging	*No*			
2	Charging-Blasting	*Yes*	After charging, before initiate the blasting all persons and machines should be evacuated to the safe locations and it takes some time (around 20 min)	Cannot take any actions to reduce	
3	Blasting-Mucking, Scaling & Breaking	*No*			
4	Breaking – Loading	*No*			
5	Loading – Transporting	*No*			

6	Transporting – Processing	*No*			

g) What is the current production cycle time?

After drilling is completed blasting is done in the next day. So with the crushing to be completed, it would take about 3 of 8 hour working days.

h) What are the actions (strategies) taken to reduce cycle time?

Increase machines and manpower

3.3. Unnecessary Transportation

i) Briefly explain about internal and external transportation use in the site.

Use Methods	**Approximate distance**	**Is there any possibility of reducing distance?**	**If there is a possibility, how to reduce?**
Internal transportation			
1.Blasted rock transportation from quarry to crusher plant.	*100 m*	No	
2.Crushed aggregate transport from crusher stock pile to selected temporary stock piles.	*100-200m*	Yes	Increase the crusher space
3.Diesel transportation from Diesel tank to generator	*60m*	No	
4.Explosive material transportation from site magazine to quarry	*100-300m*	No	
5.Site watering by Water bowser	*2 Km*	No	
External transportation			
1.Explosive transportation from supplier to site	*35Km*	No	
2.Production delivery from site to construction site.	*Vary with site location*	No	

3.Diesel transportation from nearest fuel station to site	*12Km*	No	
4.Material transportation from nearest town centers to site	*23Km*	No	
5.Transportation of damaged parts of machines and vehicles from site to company main workshop.	*60Km*	Yes	Install a proper workshop inside the site premises.

j) Are there any delays in above transportation methods?
No

k) If there is a delay what are the reasons?
N/A

l) Propose actions/ strategies/ suggestions to reduce delays?
N/A

m) Is there any intermediate storages/ double handling occasions?
Yes, there is double handling

n) If yes, what are the reasons for double handling?
Jaw of the original crusher broke down and as an instant solution used the mobile jaw crusher of the company. However the capacity of the primary crusher (mobile crusher) is double the capacity of the secondary crusher.
Also due to the less space of the crusher stock piles, we have to stock excess production in selected temporary stock piles.

o) Is there any possibility of reducing double handling?
Yes

p) If there is a possibility, How to reduce?
Increase the crusher stockpiling space or change the crusher layout.

3.4. Unnecessary processing

g) What is the average time required and currently taking time for each stage?

Stage	**Qty**	**Average time required**	**Actual time**
Drilling	*12 feet hole*	*15 -20 min*	*15-20 min*
Charging & Blasting	*60 holes*	*2 hr*	*2 ½ hr*
Mucking, Scaling &Braking			
Loading	*3 cube*	*6 min*	*10 min*
Transporting			
Processing/ Crushing		*300 cubes per day*	*270cubes per day*

h) If above times do not tally with each other, what is the reason for that?

Charging and blasting can be quickened if more workers are used. And in the case of loading the increased time is due to the unskilled workers. Bore holes fill with water also cause to increase the charging time. And for processing wearing of the machine is the reason for reduced capacity.

i) What kind of strategies can be taken to tally these times?

By requiting required number of skill workers.

Also currently use crusher plant is almost 75 years old. So now it is time to sell this and install a new plant.

j) If above times are tally with each other, what kind of strategies are already used?

Workers engaged in drilling operations are highly experienced.

k) Are there any inappropriate production/ processing steps in this site?

No, all steps are necessary

l) If yes, do you have taken any actions (strategies) to eliminate those?

N/A

3.5. Excess Inventories

d) What is the minimum required and currently use of inventories to achieve present demand?

	Item	Minimum requirement	Current availability
Machineries			
1.	Rock drilling machine/ Track drilling machine	*3*	*3*
2.	Air Compressor	*4*	*3*
3.	Excavator	*4*	*4*
4.	Breaker	*2*	*2*
5.	Loader	*1*	*1*
6.	Exploder	*1*	*1*
7.	Dump trucks	*3*	*2*
8.	Double cab/ Jeep	*1*	*1*
9.	Vibrating feeder	*1*	*1*
10.	Jaw crusher	*1*	*1*
11.	Cone crusher/ Impact crusher	*1*	*1*
12.	Vibrating screen	*2*	*2*
13.	Generator	*1*	*1*
14.	Water bowser	*1*	*1*
15.	Any other	-	-
Material			
1.	Drill bits		Normally keep one week stock and maintain material check list to identify the availability.
2.	Drill rods		
3.	Ammonium Nitrate		
4.	Dynamite/ Water gel		
5.	Electric/ Plane detonators		
6.	Fuel		
7.	Grease		
8.	Hydraulic Oil		
9.	Engine oil		
10.	Any other		

e) If above numbers do not tally with each other, what is the reason for that?

While three air compressors are being used in operations, a fourth one is needed as a standby to use in any emergency situation.

Also, there is a Volvo 5.5 cubes dump truck for rock transport from quarry to crusher plant, but its capacity and fuel consumption are very high. This is also better unnecessary one and enough to use 3cubes dump trucks (2 nos.).

f) Do you have any actions/ strategies to keep minimum requirement?

Air compressors are supplied by subcontractors. So whenever a breakdown occurs, I inform the subcontractor and he immediately replaces it with a good one.

3.6. Unnecessary Movement/Motion

	Exploitation / Quarrying stage		**Processing / Crushing stage**	
	Machinery Movements	**Human Motions**	**Machinery Movements**	**Human Motions**
Types				
Are there any unnecessary… …….? (Eg: Turning, Lifting, Reaching, Traveling/ looking for parts, tools, helps, etc.)	Yes	Yes	No	Yes
If yes, What are those?	*Unnecessary traveling of excavators when mucking start in the wrong side.*	*During a machine maintenance workers move from site to store several times for looking tools, parts and materials*		*at the time of crusher plant repairing, some operators, mechanics and helpers traveled from crusher site to store several times*

What are the reasons for these movements/ motions?	*Misinformation*	No separate tool box for machines, not use record books		*Not initially identifying reason for the breakdown and not using of record book.*
Is there any possibility to reduce these movements/ motions?	Yes	Yes		Yes
If yes, what are the strategies taken to reduce?	*Set up a proper flow for site information*	*List out the tools needed for the maintenance and bring them at once. Should maintain a proper record of materials, tools need*		List out the tools and materials needed after properly identify the issue and bring them at once. *Also we don't have a store keeper to maintain store well and if it is maintained properly*

3.7. Defects

m) Which production categories are demanded by the customers?
ABC, Asphalt aggregates, Concrete aggregate, C1 and Boulders

n) What are the quality requirements expected by the customers in each category? *Specially sample size, grading of the sample, AIV and LAAV*

o) What actions are currently taking to maintain relevant qualities?
Sieve analysis test is caring out tow vise a day for each stock pile in crusher plant to check the sample size and grading of the sample. If there any

changes we do corrective actions immediately. Also crusher settings are check every day before stat the crushing activities.

p) How to eliminate the adding of foreign materials / impurities to the production?

Before start the drilling activities, all overburden soil and weathered rock layers are removed properly by using excavators and manually as per the site condition.

q) Is there any possibility to arise quality issues in production? Yes

r) If yes, what are those? and what actions (strategies) can be taken to eliminate these issues?

If we checked the crusher settings daily, those can be vary suddenly. Because it depends on the mechanical system and hydraulic pressure. Also our crusher plant now very old. Therefore can occur changes of sample size and grading.

Damage of sieves in screen can be happen any time and it also cause to arise quality issues. Uneven loading also cause to quality issues. Therefore close monitoring and supervision is important. Also maintain check list to do relevant changes and mentainenace as necessarily can be applied.

Also small particles like dust (0-5mm size) settle down on the stock pile due to raining. Sometimes dust can be removed from the pile with rain water stream. In this type of situation grading of the sample can be completely change, but this issue cannot be avoided due to the aggregate mining industry is an open environment business.

s) Is there any possibility to reject the productions due to poor quality?*Yes*

t) Has your organization faced to that type of occasions? *Yes*

u) If your organization would have to face these types of occasions, how to handle rejected productions?

Two months before we supplied our ABC to one road construction project. After we supplied around 1000cubes to their, they said its sample grading is little bit change their expectations. Then we mobilized our mobile crusher to their and crushed again in same location.

v) Is there any scrap production in your site? *Yes, but some times*

w) If yes, do you have any suggestions (strategies) to minimize this scrap production?

Sometimes scrap crusher production can be happened due to customer demand mix design does not tally with crusher production. Actually, it cannot be avoidable. So it is difficult to give any suggestions to minimize it.

x) Do you think that any repairs of machines and/ or plant is a solution for maintain production quality?

Yes. Our crusher plant is now very old. So crusher variation and breakdown has happen normally. So it is necessary to do full repair or installation of new crusher plant.

3.8. Underutilized people

n) What are the minimum required and currently using employees for each stage to achieve present demand?

Stage	**Minimum requirement**	**Actual availability**
Drilling	*9*	*9*
Charging & Blasting	*10*	*7*
Mucking, Scaling & Braking	*9*	*7*
Loading	*5*	*5*
Transporting	*5*	*5*
Processing/ Crushing	*14*	*12*

o) If above numbers do not tally with each other, what is the reason for that?

The company does not hire enough workers. For blasting operation, foreman should be there. But I do not have any truest in hired foremen and the company also does not have any policy in recruiting foramens.

p) Do you have any actions/ strategies to keep minimum requirement?

Only the action is hiring required employees.

q) Has each employee got target to achieve? Please explain those?

No individual targets are given. Only an overall project target i.e. to complete 9,000 tons of boulders by April 8.

r) Do you have any employee controlling process to reach their targets?

No controlling process. Have a friendly employer – employee working relationship. It's enough to explain about the required work to be done. The worker does it to his best.

s) Do you have any monitoring program to compare performance against targets?

No monitoring program. Just casually take that 12 loads of 15 tons per day is enough to achieve target.

t) How are their performances?

Performance is in satisfactory level. It is enough to mention about the requirement.

u) If they cannot achieve their targets, what are the reasons for that? What type of corrective actions can be taken? *N/A*

v) If they can achieve their targets, which methods can be implemented to increase the progress of work?

It is better if the company can give them a bonus for achieving targets.

w) Does this business culture de-motivate the employees?

Yes it is.

x) If yes, please explain the situation?

Once the company gave a difficult target to achieve. But the employees work hard and achieve the target somehow. But the said bonus was not given still for two months. Also even though these employees work hard all day, they are not satisfied with the salary. On the other hand the company is a well-known one. But if outsider comes into the site, he cannot even recognize the office. Also accommodations of workers are within the site hence it gives an unpleasant look for the working environment with cloths hanging around the site. Also it is unhygienic for the workers because they have to live the dust.

Site safety also not satisfied. It should be improved in all areas. Initially awareness program should be conducted due to lack of knowledge about safety in every one. Also cannot be satisfied about the safety sign boards in *the site. Also there are no fire extinguishers placed in the site and no any trained person about fire protection. Also our explosive magazine is not in a proper location. It is installed much closed to the office premises. Even the top management was informed about that but they do not expect to remove it to a safety location.*

y) As you believe, is this project use their employee creativity, physical skills and abilities in success to reach to the project goal?
Employee creativity is not being used. But their physical skills are properly identified and let them work accordingly.

z) Please explain those situations?
The company does not have any talent building policy. On the other hand all employees are given an overall training on every site work. Hence every worker is able to perform every work in the site.

ANNEX C