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Studying construction site wastes based on lean thinking on selected Addis Ababa building construction sites: A case study

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Studying construction site wastes based on lean thinking on selected Addis Ababa building construction sites: A case study

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DECLARATION

I declare that this thesis entitled "STUDYING CONSTRUCTION SITE WASTES BASED ON LEAN THINKING ON SELECTED ADDIS ABABA CONSTRUCTION SITES" is my original work. This thesis has not been presented for any other university and is not concurrently submitted in candidature of any other degree, and that all sources of material used for the thesis have been duly acknowledged.

Candidate:

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Acknowledgments

Though my name appears on the cover page of this paper, a great many contributed to the outcome. First and for most I would like to thank the almighty God for his guidance and protection. My deepest gratitude goes to Prof, (Dr.-Ing) Abebe Dinku for his valuable advises and great commitment during lecture and consultation hours. I would also like to thank Dr. Abraham Assefa for his constrictive comments and material support. I am very thankful to my elder sister Herani Sahlu for her valuable advises and for her technical and moral support all the way. I am also very thankful to my cousin Ato Abel Berhanemeskel for his material and technical support. I am also grateful to my younger brothers Asher Sahlu and Ameil Sahlu for their technical supports. I would also like to thank my wonderful parents for their love and support. Last but not least I would like to thank all the project managers at construction sites for their cooperation.

Abstract

In recent years waste in the construction industry has been the subject of several research projects around the world. Researchers implement different methods to reduce the amount of waste in construction industry. One of the effective methods is application of lean approach to construction industry. Lean construction is a result of the introduction of a new form of production management. Although lean construction is still evolving, the generic principles, techniques and tools of lean construction can already be applied. Waste reduction in order to improve performance is one of the basic concepts of lean thinking. In general, project managers tend to conceptualize "waste" as physical construction waste, but there are noticeable wastes in the construction processes which are named "non -value adding activities (NVA)" by lean construction theory. In addition to stressing on the physical waste, lean thinking specifically pay lots of attentions to the waste produced over a construction process. Waiting time, non -value adding works and material transportations are categorized in this group.

This research is based on studying construction site wastes based on lean construction concept on selected Addis Ababa construction sites. At first three major activities were selected (rebar work, concrete work and column work) then two case studies were conducted for each of the selected activities to identify and categorize each workers activity in a crew member based on lean concept of waste, afterward the case studies are compared. In general six case studies at six construction sites were conducted. In addition questionnaires were distributed among project managers on construction sites where the case studies were led in order to perceive full understand on how they comprehend construction wastes. After analyzing all the collected data conclusions and recommendations were made based on the analyzed facts.

The key finding of this research is that in almost all case studies conducted, working times spent on non-value adding activities took considerable amount of time. In addition among the non-value adding activities waiting time overcomes taking the biggest share in almost all case studies, this refers to an interruption of flow in the work process due to various reasons, like late delivery of materials, tools and equipment to construction sites, moreover waiting times indicates excessive allocation of workers which led to unproductive working hours (doing noting).In addition case

studies result shows that using better technologies (machineries and materials) contributed to less waiting time, less unnecessary transportation of materials by workers, less defect and reworks on construction sites. Also analyzed facts showed that wastes that arise out of unnecessary stock of construction materials (inventory) can possibly be avoided by having separate workshops, using ready mix concrete and modular elements. In addition time spent on non- value adding but required activities like temporary work and supporting activities (formwork) can also be minimized by using better technologies(materials and equipment), plus associated NVA activities like waiting time, defective work and re-works can also be avoided. This research also showed that construction wastes are seen as only physical wastes (material wastes) by the companies where the case studies were conducted.

Key words: - Construction waste, Lean construction, Lean thinking, Lean principles, Value adding (VA), Non -value adding (NVA) and Non -value adding but required (NVAR)

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Abbreviations

AEC = Architect, engineering and construction

CII = Construction industry institute

IMVP = International motor vehicle program

JIT = Just in time

LCI = lean construction institute

LPDS = Lean project delivery system

LWS = Lean work structuring

NVAR = Non value-adding bur required

NVA = Non value-adding

PPC = Percentage of planned and concluded items

Pus = Production units

SQC = Statistical quality control

TFV = Transformation flow, value

TPS = Toyota production system

TQC =Total quality control

TQM = Total quality management

TWSA = Temporary work and supporting activities

VA = Value adding

WIP = Work in-progress

ZIP= Zero inventory policy

CHAPTER ONE

INTRODUCTION

1.1 Background

Since 2001, the construction industry in Ethiopia has been developing tremendously. Recent studies indicated that the GDP contribution of the industry has been raised to 5.6% and approaches to the sub Saharan average 6% (Zewdu & Aregaw 2015). Meanwhile, the Gross Domestic Capital Formation (GDCF), which was about 60 percent in 1996/97, has reached nearly 75% in 2002/03. Beyond its contribution to the nation, the industry is also the 6th major contributor of the content infrastructure stock following South Africa, Egypt, Morocco, Algeria and Nigeria (S. Report, "Construction in Africa.").

Now a days the construction industry in Ethiopia has been providing a wide variety of buildings, ranging from houses to high rise buildings and from schools and hospitals to factories and shopping centers, and has been carrying out an equally wide variety of engineering construction projects, ranging from highways to hydro – electric dams and irrigation dams / canals. Construction in Ethiopia has also been affording various job opportunities. It keeps employees working full time, and thus, enables many to work over 40 hours a week to earn more money. The workers in the industry even sometimes work evenings, weekends, and holidays to finish a job or take care of an emergency or offset the disruption caused by rain, snow, wind, etc. since much of the work is done outside or in partially enclosed structures (Central Statistical, 2009).

Despite the construction industry's significant contribution to the economy of developing countries and the critical role it plays in that countries development, the performance of the industry remains generally low. Moreover, the development of the construction industry in developing countries generally lags far behind from other industries in those countries and their counter parts in developed nations. Generally, the construction industry in developing countries failed to meet expectations of governments, clients and society as a whole (Yimam, 2011).

Similar to the case with other developing countries, the Ethiopian construction industry shares many of the problems and challenges the industry is facing in other developing countries, perhaps with greater severity. Given the critical role, the construction industry plays in Ethiopia and other developing countries, and the poor level of performance of the industry in those countries, improving the performance of the industry ought to be a priority action. As contractors are one of the key players in the industry and the makers of the final product, any development and improvement initiatives in the industry has to consider ways of improving the capacity and capability of the contractors (Yimam, 2011).

Construction takes in some common considerations such as design, finance, environment, energy, and other elements. It is procured privately or publicly utilizing various delivery methodologies, including hard bid, negotiated price, traditional dealings, management contracting, etc. As construction codes have come into effect in recent years, new construction technologies and methods have emerged. The newest methods of construction improve efficiency, performance and reduce construction waste (Central Statistical, 2008/09).

1.2 Statement of the problem

As per Aziz and Hafez (2013), several partial studies from various countries have confirmed that waste in the construction industry represents a relatively large percentage of production costs. Furthermore, they argued that "the existence of significant number of waste types in the construction industry has depleted overall performance and productivity in the industry, and certain serious measures have to be taken to rectify the current situation. In addition Formoso et al. (2002) recommended broader definition of waste to include not only material waste but also waste generated in a construction project such as waiting times, unnecessary transportation times, and etc. This issue (non-physical waste within construction processes), is the basis of waste concept from lean construction approach. In Ethiopia several partial studies were coducted both on undergraduate and postgraduate level, on construction material wastes by; Getachew (2009), (Mulualem, Negatu and Tedla (2012), Esikedar (2016), Addise, (2005), Asmara (2015) and so many more. This indicates that focuses has been given only to construction material (physical)

wastes. Thus this research is based on a thought identification and categorization of the construction wastes based on lean construction systems on selected building construction sites and making cases for and how these lean ways of wastes categorization could take hold in the Ethiopian Construction Industry.

1.3 Objectives

1.3.1 Main objective

The main objective of this thesis is to identify and categories construction site wastes based on lean thinking on selected Addis Ababa building Construction sites.

1.3.2 Specific objectives+

1. Identifying and categories each crew member's activity on a certain task based on lean concept of value stream i.e. (Value adding (VA), non-value adding but required (NVAR), and non-value adding (VA) activities) on selected activities and construction sites.
2. To compare same activities but at different sites, to see if different mechanisms used by the selected companies have an effect on workers while executing (value adding (VA), non-value adding but required (NVAR), and non-value adding (VA) activities.
3. To study on how selected construction site managers understand construction site wastes.
4. To recommend and give direction towards implementing lean thinking, specifically focused on waste management.

1.4 Structure of the thesis

Chapter 1 contains introduction to the Ethiopian construction industry, the research objectives, and structure of the paper, research design, methodology and the limitation and scope of the research. Chapter 2 provides a literature review on lean construction and its techniques. Chapter 3 discusses the methodologies used while conducting the research. Chapter 4 presents analysis of the Case studies and questionnaires on selected Addis Ababa Construction sites based on the Lean Construction Ideal focused on waste management. Chapter 5 summarizes conclusions based on

the results of the research and an attempt of practical recommendations. References and appendices are provided at the end of this research.

1.5 Research design

It has been already recommended that broader definition of waste to include not only material waste but also waste generated in a construction project such as waiting times, transportation times and so on. (Formoso et al., 2002).Nonetheless, the focus has been on material waste, which tends to be one among the resources in construction process (Rahman et al., 2012). Therefore this research is based on a thought identification and categorization of the construction wastes based on of lean construction concept on selected building construction sites and making cases for and how these lean ways of wastes categorization could take hold in the Ethiopian Construction Industry.

The case for lean construction and waste management is well established in the literature review part – which clearly defines those lean process components. What remains is a logical and strategic identification and categorizing of construction wastes based on lean thinking i.e. VA NVAR and NVA on selected construction sites. In doing so – the research was able to establish the following facts as guides in undertaking the research. But the research is not liable to offer any scientific means to support the below listed 'facts'.

- Previous researches performed on construction wastes mainly focus on construction materials (physical wastes).
- The researcher strongly believes that Construction Companies should take the first steps in understanding non- physical wastes that are (Overproduction, Time on hand (waiting), Transportation, Additional/Inappropriate Processing, Inventories, Movement and Making Defective Products) that exists on construction sites.
- Identifying and categorizing of non- physical wastes on construction sites is a very challenging task which requires a close examination and observation of each crew members' activity using different techniques like video recordings and site observations

which would require the willingness of construction companies and the workers to be recorded while performing a specific activity .

- According to Rahman et al. (2012); some of the non –physical wastes like over processing can be avoided by changing the techniques used by the construction companies. In order to make a point, different case studies should be done at different construction companies using different techniques and machineries.
- Taking the above facts into consideration the research's case studies will only need to focus on the largest construction companies in the country as is established by Ministry of Urban Development, housing and Construction. This would mean selected GC-1 contractors.
- Assuming the major activities of any structural building are rebar work, concrete work and formwork, activates observed on construction sites need to focus on these activities.

1.6 Research methodology

This study was carried out in five major stages. The methodology of this thesis is summarized as below:

1. Literature study – an intensive study of previous work in the area of lean construction and waste management which assisted the study in developing implementation strategy.
2. Data Collection – methods for data collection which included direct questionnaires, case studies using video recordings and hand sheet data collection methods.
3. Data Analysis and Evaluation – a simple yet meaningful analysis of measured data and evaluation of selected companies based on Lean thinking focused on waste management fulfilled objectives of this thesis.
4. Final Report – an overview of the outcomes of study have been documented in this thesis report.

1.7 Scope and limitations

The scope of this research is confined to identifying and categorizing of construction site wastes based on lean thinking on selected Addis Ababa building construction sites. In addition the

activities observed on case studies focuses only on rebar work for slab and column, concrete work for slab and column and formwork for column. The research is constrained by the method used for data collection which includes video recording to observe each crew member's activity, this method of data collection can possibly bias real result of workers when recognizing that they are being watched under a camera, in addition it was difficult to identify and categorize some of the non-physical waste that originates from action of the workers. Another limitation of the research perhaps emanates from the fact that construction by nature involves a great number of workers moving from one part to other, this makes it very difficult to observe the entire activities of the workers being watched under a wide zoom camera recording. In addition most of the construction sites where the case studies were conducted covers wide range of area i.e., The actual construction area, as a result activities are limited by camera's view of the cycle, in order to avoid the confusion the observation has been done on specific areas where all the workers and activities can fairly be observed under a wide camera zoom, and some of the actions made by the workers were very difficult to classify under lean ways of categorizing construction waste, which as example includes doing nothing. Furthermore weather activities observed are VA, NVA or NVAR is based on the researcher's judgment.

CHAPTER TWO

LITERATURE REVIEW

This chapter consists of a review of findings from a comprehensive literature search that was conducted as part of this research as discussed in Chapter 1. A literature search was used as one of the means to understand more about existing research works on this topic and to get better knowledge of lean construction and explicitly focused on waste management. The subjects searched include (1) introduction, (2) history of lean production, (3) the diffusion of lean ideas, (4) lean in construction, (5) lean construction elements, (6) waste in lean construction and (7) literature summary and gap identification.

2.1 Introduction

Construction industry has been suffering enormously from a serious drawback, which is "Waste" (Senaratne and Wijesiri, 2008). All the research conducted in the area of construction waste imply the huge volume of waste generated during a construction project (Esin and Cosgun, 2007; Wanga et al., 2010). During last decades, various methods are utilized in order to reduce construction waste and its effects. One of innovative approaches in this regard is "Lean Construction", which was introduced to construction industry in 1990s based on a successful manufacturing theory, i.e. lean production. Actually, eliminating waste in a process is one of top priorities in lean construction theory (Mao and Zhang, 2008; Farrar et al., 2004; Dunlop and Smith, 2004; Al-Sudairi, 2007). In general, project managers interpret waste as physical construction waste, which dominantly includes material losses (Koskela, 1992). In addition to stressing on the physical waste, lean thinking specifically pay lots of attentions to the waste produced over a construction process i.e. reducing the time from start to delivery by eliminating the source of waste in the work flow is one of the basic concepts of lean enterprise. Waiting time, non-value adding works and material transportations are categorized in this group. In construction, lean techniques are used to reduce waste and increase productivity. Lean enterprise is to achieve owner expectations through the use of the absolute minimum amount of man, machine, and material. This is achieved by continuous

pursuit, identification and elimination of waste through a systematic approach that relies on team-integration and effective communication (Odomirok, 2015).

2.2 History of lean production

The answer to this question has been the diffusion of Japan's highly successful production and management system termed "lean production" (Womack et al. 1990). The term was coined by John Krafcik, a researcher on the team from the International Motor Vehicle Program (IMVP) (Womack et al. 1990). IMVP was a team organized at the Massachusetts Institute of Technology during the mid-1980s with the objective of studying the innovative techniques used by the Japanese in their highly successful automotive industry (Womack et al. 1990). The logic of using the term "lean" will become clearer as the principles are clarified. The fundamental ideas of lean production have been described under numerous names as researchers and practicing professionals have sought to study and diffuse the core ideas. Names such as World Class Manufacturing (Schonberger 1997), New Production Philosophy (Koskela 1992), Lean Thinking (Womack and Jones 1996), Just-in-Time/Total Quality Control, Time Based Competition, and many similar methods and principles have been used to describe the same fundamental collection of ideas (Koskela 1992).

The foundations of lean production were developed in post–World War II Japan, when the Japanese manufacturing industry underwent a complete rebuilding (Womack et al. 1990). Lean pioneers Kiichiro Toyoda, Eiji Toyoda and Taiichi Ohno of the Toyota Motor Company developed many of the underlying principles of lean production in response to pragmatic considerations and existing geographic circumstances. The impetus for lean production occurred when Kiichiro, president of Toyota at the time, demanded that Toyota "…catch up with America in three years otherwise the automobile industry of Japan will not survive" (Ohno 1988; Hopp 1996). At the time, limited supply of raw materials and inadequate space for inventory in Japan fostered an atmosphere in which concepts such as just-in-time (JIT) and zero inventories became necessary. During the spring of 1950, Eiji Toyoda visited American manufacturers, namely Ford's Rouge Plant in Detroit, to study mass production and perhaps look for ways to improve

the country's own rebuilding industry (Womack et al. 1990). This was the second visit to study US manufacturing practices made by the Toyoda family; the first was made by Kiichiro in 1929. What Eiji Toyoda found was a system rampant with muda, a Japanese term that encompasses waste (Womack 1996). He noted that only the worker on the assembly line was adding value to the process. Another striking feature was the emphasis placed by their American counterparts on continually running the production line. This common practice was thought to be justified by the expense of purchasing such equipment. To the Japanese, this practice appeared to compound and multiply errors, a mistake the Japanese could not afford to make Japan's labor productivity at the time was one ninth that of the United States, and it became obvious to Toyota that it could not compete with the United States by depending on economies of scale to produce massive volumes for a small market that did not have the same type of demand (Ohno 1988; Shingo 1981; Hopp 1996).

Toyota then made the strategic decision to focus its manufacturing efforts not on massive volumes of a product but, rather, on many different products in smaller volumes. In his numerous experiments focused on reducing machine setup times, Ohno, Toyota's chief production engineer, noted that the cost of producing smaller batches of parts was less than that of producing larger quantities as practiced in the United States. This was true because making small lot sizes greatly reduced the carrying costs required for huge inventories, and the cost of rework was reduced because defects showed up instantly in smaller batches (Womack et al. 1990). Ohno also managed to reduce the amount of time required for machine setup from an entire day to three minutes, a task that enabled Toyota to increase the flexibility of its production lines as well as reduce production times. The concept of JIT was developed to complement this new production philosophy undertaken at Toyota. The model for JIT was the American supermarket, a relatively new idea to the Japanese in the 1950s (Hopp 1996). The American supermarket provided customers with what they needed, when they needed it and in the right amount needed. JIT further evolved to include concepts found to be crucial to the effective operation of the JIT system and that would later become goals of the system. These concepts are referred to as the seven zeros: zero defects, zero lot size, zero setups, zero breakdowns, zero handling, zero lead time and zero surging (Hopp 1996).

2.3 Predominant types of manufacturing in the 20th century

2.3.1Conversion model versus flow model

To fully understand lean production, it is important to become familiar with the two predominant types of production systems of the 20th century. Traditionally, US manufacturing has been viewed as a mass production system focusing primarily on the process of conversions (Koskela 1992). Figure 1 (adapted from Figure 3, Koskela 2000) illustrates this basic concept.



Figure 1Conversion process [Koskela 2000]

The conventional breakdown of the manufacturing process into a series of activities, each undertaking the conversion of an input to an output, referred to as the conversion model or transformation model, is illustrated on Figure 2 (adapted from Rother 1998). This type of production system historically uses what is called a batch and queue theory (Womack 1996). Batch and queue refers to the theory that for machines to achieve a high utilization rate, they must be run continually. As a result of this, parts are manufactured in large batches at one process within a plant and then queued for the next process. Batch and queue theory leads to many manufacturing problems, such as bottlenecking and large inventories from high work-in-progress (WIP) levels (Diekmann, J.E, Krewedl, M, Balonick, J, Stewart, T and Spencer, 2004).

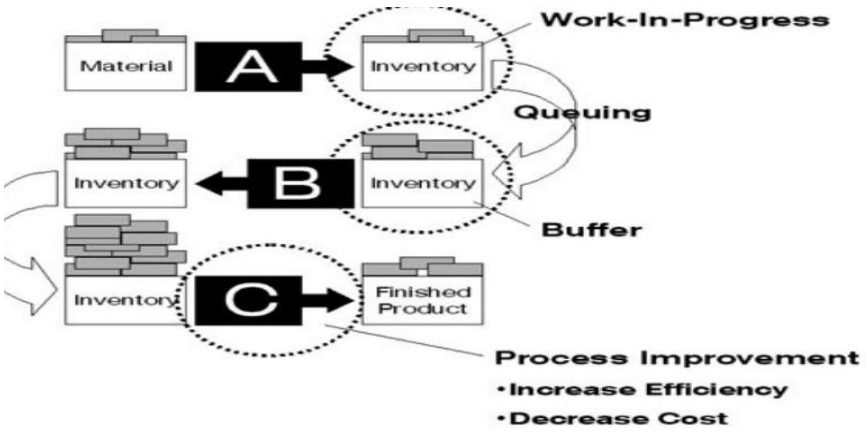


Figure 2 Transformation model [Rother 1998]

The view of production as a series of conversions is fundamentally different from the second dominant type of production in the 20th century, the view of manufacturing as a flow model (Koskela 1992). Production as a flow process is one of the core ideas of lean production. Figure 3 (adapted from Rother 1998) represents a generalized flow model of production.



Figure 3 Flow model of production [Rother 1998]

Unlike the traditional view of production, the flow process does not view the production stream solely as a series of conversions. The conceptualization of manufacturing as a flow model delineates between those activities that add value to the process (conversion) and those that do not (Koskela refers to them as flow activities) (Koskela 1992). By defining the different types of activities that occur in production, the focus of improvement does not become compartmentalized as on Figure 1, but rather envelops the entire value stream (Womack 1996). The value stream of a particular product consists of all activities and parties involved in its creation, from raw material suppliers to the customer as illustrated on Figure 4.



Figure 4 Value stream Diekmann, J.E, Krewedl, M, Balonick, J, Stewart, T and Spencer, 2004]

Examples of non-value adding activities, or muda, are large inventories, wait times, inspection time, WIP and overproduction (Womack 1996). Improvement to the system would then entail not only reducing the cost and improving the efficiency of the value adding activities, but also reducing and/or eliminating the non-value adding activities. Figure 5 (adapted from Koskela 2000) illustrates these concepts.

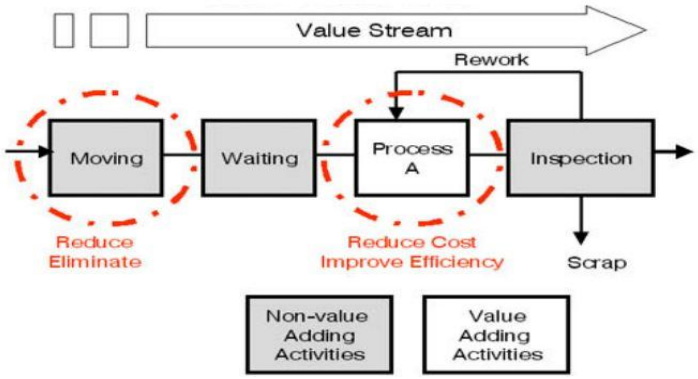


Figure 5 Value adding and non-value adding activities [Koskela 2000]

Improving the system through waste elimination and conversion activity improvement allows all elements of the entire production process to be enhanced. The flow process tends to focus on the elimination of the large buffers found within mass manufacturing by emphasizing the constant movement of components from one value adding activity to the next. This type of system, also referred to as single-piece flow (Womack 1996).

2.4 The five lean principles

Lean thinking has been summarized in the following five principles, which are the core concepts of lean production as presented by Ahmed and Forbes (2011).

2.4.1 Value

Lean thinking starts with the step of specifying value. Value is supposed to be expressed with the help of a specific product and its features defined by the customer. From the customers point of view the producer is responsible to deliver exactly what the "voice of the customer" has ordered regarding specific product attributes as price and time. For the customer something is of value what he can directly use. First of all the end customer needs to be identified. Afterwards it is the task of the producer to enable the customer to determine those features giving him the knowledge (Womack and Jones, 2003, p.16). A close relation between producer and customer is required. The concept of the customer is the basis for this specific thinking (Jørgensen and Emmitt, 2008,

p.386). The counter part of value is waste. The aim of lean is to increase the value while eliminating and reducing waste (Womack and Jones, 2003, p.15).

2.4.2 Value stream

The second principle in lean thinking is to identify the value stream, i.e. the whole set of actions required to make a specific product (whether a good, a service or a combination of both) (Womack & Jones, 2003, p. 317; Liker, 2004, p. 202). It is an action that is applied to all three major tasks of a business, 1) Problem-solving task: From concept through detailed design and engineering to production launch, 2) Information management task: From order taking to detailed scheduling to delivery, 3) Physical transformation task: From raw material to a finished product in the hands of the customer. According to Christoph Friedrich Rodewohl (2014), value stream analysis show three type of actions occurring along the value stream:

- Value adding activities (VA):Assembling engine, tightening a bolt
- Necessary but not value adding (NNVA):Inspecting welds to ensure quality
- Non value adding (NVA): activities that add no value and to be eliminated instantly

Underlying goal with the analysis of value stream is to look at the entire value stream of each product, starting from first supplier toward the ultimate customer of product. The analysis of entire value stream provide a holistic view that goes beyond a single company, it also gives the opportunity to improve the whole rather than just concentrating at own business, thus removing all the waste. This approach in terms of an organization is often called the lean enterprise (Womack and Jones, 2003). Making the lean enterprise needs new ways of involving partners and suppliers; such coordination is based on simple principles. In order to regulate the behavior between partners and make value stream transparent. Such coordination provide opportunities to remove waste and all partners will be able to verify if other partners are working according to the agreed principles (Womack & Jones, 2003).

2.4.3 Flow

The third principle in lean thinking is to create continuous flow of value creating steps. This is an important step in the whole process of implementing lean. This step requires change in thinking, a

new way of doing things which is completely different from traditional batch thinking (Christoph Friedrich Rodewohl, 2014). The goal of flow principle is based on redefining the work of functions, departments, and firms so they can make positive contribution to value creation and to speak to the real needs of employees at every point along the stream so it is actually in their interest to make value flow (Womack & Jones, 2003, p. 24). Effective accomplishment of this goal is possible through focusing on product and further creating a lean enterprise for each product coupled with rethinking conventional boundaries of careers, departments, functions and companies. Once managers learn to see flow thinking, it is possible to apply flow techniques in any activity and the flow principle remains the same in every case (Womack & Jones, 2003, p.64). Creating and maintaining continuous flow is of course a continuous challenge and also because of the focus on perfection, which is the last principle of lean and place entire system in a permanent creative tension on behalf of every worker (Womack & Jones, 2003, p. 65-66).

2.4.4 Pull production

The fourth principle of lean thinking is focused on, not only how to provide customer oriented products, and when to provide it. Toyota follows pull, this means production starts only after an order is placed by customer. Thus, the customer order is pushed backward (using Kanban) in the production process until it reaches the first stage from where the production begins (Mo, 2009). In the view of Womack and Jones, the pull principle must be applied at every step of value stream. No one upstream should produce a good or service until the customer downstream demand it. The basic strategy behind pull is that you let the customer pull the product from your company instead of pushing the product toward customer, by doing this the pile of inventories are eliminated (Christoph Friedrich Rodewohl 2014). Womack, et al. (1990) during their comparative study of automobile manufacturers, observed that there was no room for inventories at Toyota Takoka and factory hold only an hour's worth of inventory. The pull system turns production into a Just-in-time process in which materials are scheduled through pull instead of push (Karlsson and Åhlstrom, 1996). Pull consequently reduces throughput times "half in product development, 75 percent in order processing, and 90 percent in physical production" (Womack & Jones, 2003, p. 24). This creates stability as customers know that, "they can get what they want and whenever they want" (Womack and Jones, 2002, p 24). Thus, the whole system is designed in a way that supplies

are immediately ordered from the next level, and work happen in small batches. Two popular tools that are used to manage pull are Kanban and Just in Time (JIT). According to Shingo (1981) Justin-Time implies that the stock of finished products remain zero, meaning the production must equal orders. Following this rule in practice is more complicated and take companies time to understand. Having a look at the data on inventories at any given level of economic activity, inventories are not reduced enough in Europe, USA and even in Japan the application of Pull is more in Just in Time supply, not in Just in Time production. Thus, seemingly companies have more adopted the principle in supply instead of production. Thus nothing has happened except to push inventories of the same magnitude one step back toward up stream processes and raw materials (Womack & Jones, 2003).

2.4.5 Perfection

As organizations begin to accurately specify value, identify the entire value stream, make continuous flow of value creating steps, and let the customer pull the value, these four principles further lead the system toward last principle of lean thinking "Perfection" which is an alert that there is no end to the process of reducing; effort, time, space, cost, and mistakes while offering a product which is ever more nearly what the customer actually wants (Womack & Jones, 2003, p. 25). The first four principles interact with each other in a virtuous circle, thus improvements in any of these lead toward improvement in the others. For example, strong product teams that are in direct contact with customer always find ways to specify value more accurately and often find better ways to enhance flow and pull as well. New processes and technologies in manufacturing are also among ways that contribute in this context. Thus, increasing value and eliminating waste all together leading toward perfection (Womack & Jones, 2003). However, it is impossible to envision perfection, but of course "it provides inspiration and direction essential to making progress in right direction" (Womack & Jones, 2003, p.94). The most important stimulus to perfection is transparency – making entire value stream visible to everyone; subcontractors, suppliers, assemblers, distributors, customers, and employees, all of them can see everything; making value stream visible in such a way, make it easier to discover ways to create value and prevent waste. In lean organizations visual control boards are often used in production and near the assembly lines which provide instant feedback to the workers about made improvements, and

it develop further motivation among workers to continue with further possible improvements (Womack & Jones, 2003).

2.5 The diffusion of lean ideas

Lean principles have been amended and expanded over the decades by those in other industries who are transferring lean ideas and successes to their respective industries. The software, aerospace, air travel and shipbuilding industries all have extensive efforts directed at applying lean principles to improve profitability and quality and reduce waste. Lean can be used as a concept, principles, a type of ideology or a method to apply to activities or an organization management's guideline (Diekmann, J.E, Krewedl, M, Balonick, J, Stewart, T and Spencer, 2004). Lean can also be used in any parts of construction process, such as design phase, construction phase or procurement phase, in order to acquire a long-term development. Lean is also a set of principles, approaches, and methodologies that can be applied individually or organization. When lean principles are used a method to management they are continuously performed and can become a long-term philosophy for directing organizations to be easy, clear and well-managed. (Schniederjans, 2009).The architecture, engineering and construction (AEC) industry has a far-reaching, worldwide effort to apply lean principles and practices. North America, Europe and South America have organizations devoted exclusively to studying lean ideas and applying them. In fact, the efforts of the AEC industry have led the way toward innovative ideas about the application of lean thinking to the construction industry. In this way, the core idea of lean principles as originally set forth by Ohno was expanded and adapted throughout the manufacturing sector. Other management thinkers have coupled diverse management theories such as concurrent engineering and TQM to these core lean principles. "Lean theory" and "lean applications" for AEC design, procurement and production functions have received significant attention in many quarters around the world (James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, 2004).

2.6 Lean in construction

Lean construction has been defined in several ways as the concept continues to evolve. According to Antillon (2010), lean construction refers to the application and adaptation of the underlying concepts and techniques of lean production as a new philosophy of production for construction. The industry has adapted this production model as a means for improving its performance and reducing the waste that tends to exist in the construction industry. Lean production focuses on the reduction of waste, increase of value to the owners, and continuous improvement. Several of these lean production concepts and techniques have been successfully implemented in the construction industry from which effective lean construction tools (Antillon, 2010).

The Construction Industry Institute (CII) has defined lean construction as "the continuous process of eliminating waste, meeting or exceeding all owner requirements, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project" (CII Lean Principles in Construction Project Team, PT 191). As per Ahmed and Forbes (2011) and Koskela (2002) described lean construction as "a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value for the customer (both internal and external)" (p.45).

Bertelsen (2002) expanded the manufacturing model of lean to include the ideas of construction as one-of-a-kind production, construction as a complex system and construction as cooperation. Ballard and Howell (1998) in their paper, "What Kind of Production is Construction," describe differences between manufacturing and construction. In the United Kingdom, the Construction Task Force produced "Rethinking Construction" (The Egan Report) that applies the lessons of the manufacturing revolution to the construction sector in the United Kingdom. Another innovation in the application of lean theory to construction was the development of the Last Planner (Ballard 2000a) that emphasizes reliability in the planning function. Others (Matthews 2003; Ballard 2002c; Tommelein 2003; dos Santos 1999) have addressed the impact that lean principles have had on contracts, project delivery and project supply chains.

In the United States, Glenn Ballard and Greg Howell founded the Lean Construction Institute (LCI) in August 1997 (Lean Construction Institute, 2010). LCI's goal is to develop, through

research, knowledge regarding project-based production management in the design, engineering, and construction of capital facilities.

According to Johnston and Brennan (1996), Koskela (2000), Koskela and Howell (2001), Ballard and Howell (1994), the traditional approaches to construction or the conventional project management approaches have inadequacies in resolving the problems in the industry. Nevertheless, lean manufacturing principles and techniques provide the foundations for minimization or total elimination of the waste faced by the industry. Lean construction has change the traditional view of labor flow and work flow reliability which were considered the most determinants of constructions works and has embraced the concept of flow and value generation. Basically, lean construction aims at reducing the wastes in workflow which the conventional methods are inadequate to eliminating them (Richard Hannis Ansah, Shahryar Sorooshian and Shariman Bin Mustafa, 2016).

Koskela (2000) argued that, there is a mismatch between the conceptual models of project management and the reality observed. This highlight lack of robustness in the existing managements concepts and therefore calls for production theory in construction. This new approach must rest on the expanded Transformation (T), Flow (F), and Value generation (V) foundation to optimize performance in projects.

There are among others three distinguishing features between LC practice and conventional project management, specifically: a) LC concentrates on waste reduction in construction processes; b) LC seeks to minimize irregularity and variability so that there will be flow of material and information in processes without any interruptions; and c) LC uses pull system: materials for construction is expected to be delivered on site just when it is required or needed (Abdul Rahman *et al*., 2012).

2.7 Lean Construction Elements

Lean production has several tools and techniques that have evolved since the beginning of its application in the construction industry. These tools and techniques continue to develop as more understanding and experience develops. Lean construction has been identified as trying to develop a list of the most prominent and exhaustive tools and techniques that are being implemented in

today's construction industry and that might also impact performance practices. Some of the tools related to the topic of study are: TFV theory, last planner, just-in-time and lean project delivery system. The implementation of such lean tools and techniques had significantly reduced waste and improved performance in construction projects (Rodewhol, 2014).

2.7.1 Theory of production management

It is generally acknowledged that managements of projects must endeavor to achieve the goals of projects that were agreed upon before the start of the project. They must utilize and deploy tools, skills, techniques and available resources to facilitate projects to be able to complete projects on time. An effective and efficient project management will help meet and even exceed the expectations of the customer, they will maximize the use of available resources; be it time, money, people, space, among others, and endeavor for a successful completion of project within budget and on time; they will instill confidence in their team and also file what has been done for references in the future (Glenn, 2007). However, according to Abdelhamid (2004), there have been observations and evidence that have indicated that, the models behind construction management and project management tools like; critical path method; work break down; and earned value management; have failed to complete project within budget, on time and the quality desired for the project. The failures of current project management help define the requirements for a new approach. This was echoed by Koskela (2000) who argued that, there is a mismatch between the conceptual models of project management and the reality observed. This highlight lack of robustness in the existing managements concepts and therefore calls for production theory in construction. This new approach must rest on the expanded Transformation (T), Flow (F), and Value generation (V) foundation to optimize performance in projects.

- A Transformation (T) of raw materials into standing structures,
- As a Flow (F) of the raw material and information through various production processes, and
- As Value (V) generation and creation for owners through the elimination of value loss (realized -outcome versus best possible).

2.7.1.1 Managing Transformation

Managing transformation is the kind of project management most project managers are familiar with. It takes place by managing contracts, establishing quality and safety requirements and procedures, and it frequently leads to what seems to be an increase in productivity but in truth is sub-optimization only. It is necessary to manage the transformations in construction if for no other reason than because of the huge contract values involved, but this simplistic kind of project management is not adequate in the complex and dynamic system the project usually represents (Bertelsen and Koskela, 2003).

2.7.1.2 Managing Flow

Managing flow in the construction industry introduces several new management activities. One should be to establish a closer cooperation along the supply chain – Supply Chain Management has this been coined in the manufacturing industry. This kind of cooperation should not only comprise cooperation between main contractor and contractors, but should comprise the manufacturers and suppliers of construction materials as well. Another activity should be setting up the logistics for materials and information. Bertelsen and Nielsen (1997) report the effects of such procedures in practice and Vrijhoef and Koskela (1999) investigate the aspects from a management point of view. The method of Last Planner (Ballard 2000) can also be seen as an important tool in managing this cooperation and the logistics during the construction phase.

2.7.1.3 Managing Value Generation

The concept of value is probably the most difficult to approach in the new way of managing construction projects. Green (1996) proposes an understanding of the value generation during the early design phases as a learning process between the client and the design professionals. Both parties learn and through this a joint understanding of client's value parameters and their realization in the design is reached. Christoffersen (2003) reports the successful implementation of a systematic value management as proposed by Bertelsen et al (2002) in order through the project life cycle to make sure the specified value is delivered, whereas Green (1996) introduces value engineering as the task of generating the specified value with the lowest costs.

2.7.2 Just-in-Time in Construction Environment

The concept of Just-in-Time (JIT) originated in Japan in the early 1950s and was developed in the supply chain arena by Taichi Ohno and his fellow workers at Toyota who realized that excess inventory stocks created cost and production problems (Opfer, 1998, p. 10). JIT is a controlling procurement process through developing a systematic program that must be followed in order to reach optimum efficiency. Just-in-Time (JIT), or Zero-Inventory-Policy (ZIP), is a production and delivery technique with an objective of continually minimizing and eliminating any type of waste or excess (Pheng & Hui, 1999, p. 657).

The construction environment is complex and involves many activities that require excessive collaboration and coordination between the professionals who take part in the process. This differentiates the construction industry from the manufacturing process where JIT assists manufacturers in supplier selection and evaluating their performance (Aksoy and Öztürk, 2011). Nevertheless, both the manufacturing and construction industries require active movement of materials from the suppliers to the production area in both the factory and the worksite (Mohamed Ali and Salwa Beheiry, 2015).

The main goal of JIT materials management system in construction project is to optimize materials delivery timing and to minimize inventory quantities. Materials inventory or storage on site are exposed into certain deficiencies such as protecting it against theft, damage, and weather, and failing to provide space for materials. The implementation of JIT in construction requires commitment from staff and crew involved in the construction in terms that all parties from the planning and site should collaborate together and participate in the decision making process. The successful implementation of JIT is dependent on the suppliers' flexibility, users' stability, total management and employee commitment as well as teamwork (Mohamed Ali and Salwa Beheiry, 2015).

2.7.3 The integrated agreement for lean project delivery

Traditionally, facility owners have been presented with a standard set of project delivery options: design-bid-build, construction management (agency or at-risk), or design-build. Despite this range of options, many owners remain dissatisfied: projects take too long, they cost too much, and the

work fails to meet quality expectations (William A. Lichtig, 2006). The Integrated Agreement for Lean Project Delivery offers improved project performance both from the owner's perspective (reduced cost and time, improved quality and safety) and from the viewpoint of the designers and contractors (increased profit and profit velocity, improved safety, and employee satisfaction). While the jury is still out, early results are very promising (Michigan State university, White paper, 2008).

The Lean Project Delivery System (LPDS) is a conceptual framework developed by Ballard (2000) to guide the implementation of lean construction on project-based production systems, i.e., the structures we build. The LPDS was developed as a set of interdependent functions (the systems level), rules for decision making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate (Michigan State University, White paper, 2008).

Figure 6 illustrates the LPDS as originally depicted in Ballard (2000). LPDS is shown as a series of overlapping triads, and within each triad different processes are to be completed.

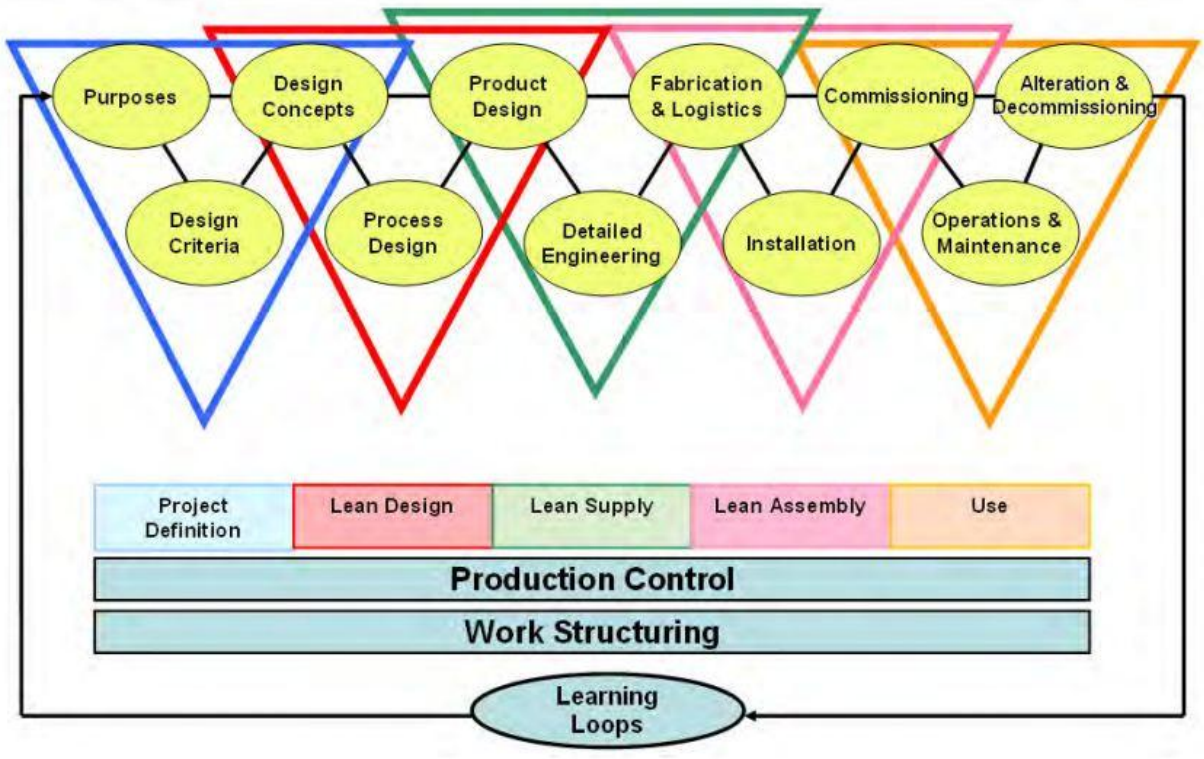


Figure 6 Lean delivery system [Ballard, 2000]

According to Michigan State University, White paper (2008), The triads and the processes contained within them are as follows:-

- The Project Definition phase consists of the modules: Needs and Values Determination, Design Criteria, and Conceptual Design.
- Lean Design consists of Conceptual Design, Process Design, and Product Design.
- Lean Supply consists of Product Design, Detailed Engineering, and Fabrication/Logistics.
- Lean Assembly consists of Fabrication/Logistics, Site Installation, and Testing/Turnover.
- Production Control consists of Work Flow Control and Production Unit Control.
- Work Structuring and Post-Occupancy Evaluation are thus far only single modules.

Essential features of LPDS include:

- The project is structured and managed as a value generating process
- Downstream stakeholders are involved in front end planning and design through cross functional teams
- Project control has the job of execution as opposed to reliance on after-the-fact variance detection
- Optimization efforts are focused on making work flow reliable as opposed to improving productivity
- Pull techniques are used to govern the flow of materials and information through networks of cooperating specialists
- Capacity and inventory buffers are used to absorb variability
- Feedback loops are incorporated at every level, dedicated to rapid system adjustment; i.e., learning.

As depicted in the LPDS graph each phase of the project overlaps with the adjacent phases indicating the need to incorporate interests of the subsequent phases. This is the major departure of the LPDS from the traditional project delivery systems, where construction details are thought of only after the project has been bid. The different phases of LPDS provide different areas of

improvement within a project delivery system. Although all the phases are crucial for success of a lean project, the heart of the LPDS lies in Work structuring and Production Control (Abdelhamid 2008).

2.7.3.1 Work structuring

"Work Structuring" is a term created by LCI to indicate the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and possible off-site fabrication opportunities. The purpose of work structuring is to make site operations flow in a reliable and quick manner while delivering value to the customer.

Work structuring is the most fundamental level of process design, answering the following questions (Ballard 2000):

- In what chunks will work be assigned to specialist production units (PUs)?
- How will work chunks be sequenced through various PUs?
- In what chunks will work be released from one PU to the next?
- Where will decoupling buffers be needed and how should they be sized?
- When will the different chunks of work be done?

In essence, works structuring is thinking production process during product design. LWS can be accomplished using a myriad of tools such as BIM, Target Costing, set-based design, CPM, simulation, etc. This level can be easily achieved by a design/build arrangement where the architect and the contractor work toward meeting the spirit of LWS, which is to think production during design. (Michigan State University, White paper, 2008).

2.7.3.2 Production control

Production control governs execution of plans and extends throughout a project. "Control" first of all means causing a desired future rather than identifying variances between plan and actual. Production control consists of work flow control and production unit control. Work flow control is accomplished primarily through the lookahead process. Production unit control is accomplished primarily through weekly work planning (LCI Website). The Last Planner system on Figure 7 is central to the process of production planning and control.

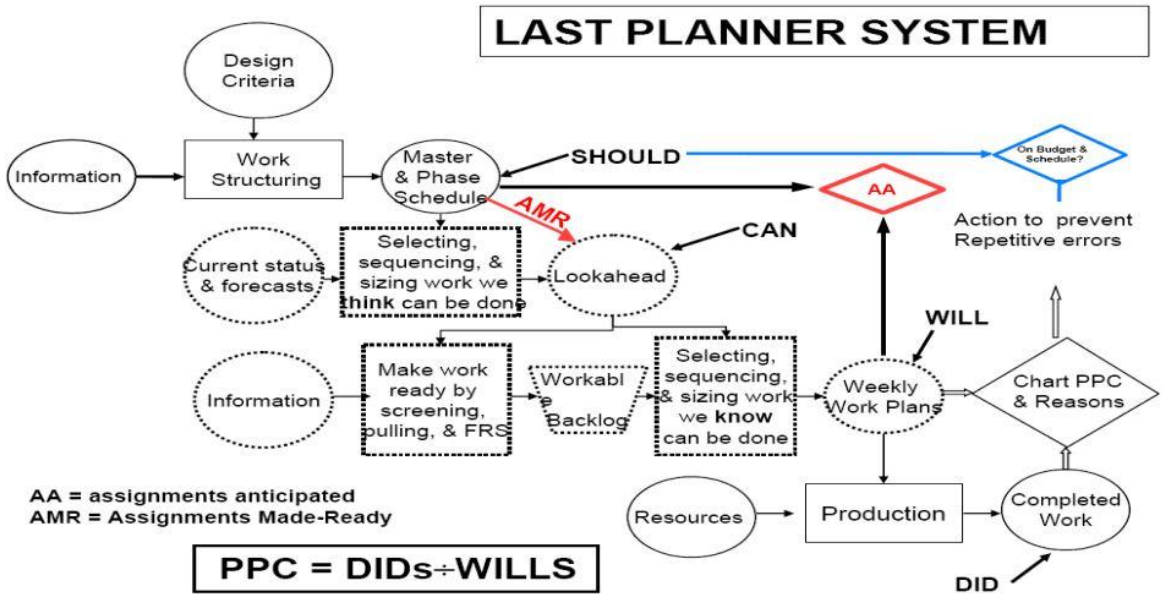


Figure 7 Last planner system [Ballard, 2000]

During the front end planning process, a master schedule is developed and serves to demonstrate the feasibility of project completion by the target end date. A higher level of level of detail at this point is inappropriate because of uncertainty regarding the future. Master schedules are expressed at the level of milestones, typically by phase. Phase schedules are produced by cross functional teams using pull techniques closer in time to the scheduled start of the particular phase. Phase schedules feed into lookahead windows, usually 3 to 12 weeks in duration. The Lookahead process is screening processes wherein scheduled tasks are made ready for assignment by ensuring that no constraints exist that would prevent the task from resuming. These ready and constraint-free tasks are placed in a Workable Backlog. The lookahead process generates early warning of problems so there is more time to resolve them (Michigan State University, White paper, 2008).

Weekly work plans are weekly production assignments, established based on the ability to perform them and not only based on what "should" be done. To measure the effectiveness of the production system to carryout assignments (commitments), the number of completed assignments is expressed as a ratio of the total number of assignments committed in PPC can take on values from 0 to 100%, with the latter being the best case. A high PPC reflects a well-planned production process with high workflow reliability between production units. A PPC less than 100% reflects a failure in the

production planning process. Understanding the reasons for the failure will enable future improvement of the planning process formed by selection of tasks from Workable Backlog (Michigan State University, White paper, 2008).

To get the highest level of reliable workflow on a construction site, which leads to cost and time savings, then all levels of the LPDS cone need to be used. If the first level is used, i.e., Production Control, then reliable workflow will be achieved but not as high or consistently as when the second level and third level are implemented (Abdelhamid 2008).

2.8 Waste in lean construction

Lean construction is aimed at improving construction performance by eliminating wastes that do not add value to the customer. Although there are still debates about whether the productivity of the construction industry is increasing or declining, the performance of the construction industry is widely perceived as unsatisfactory when compared with many other industries as shown in figure 8 below.

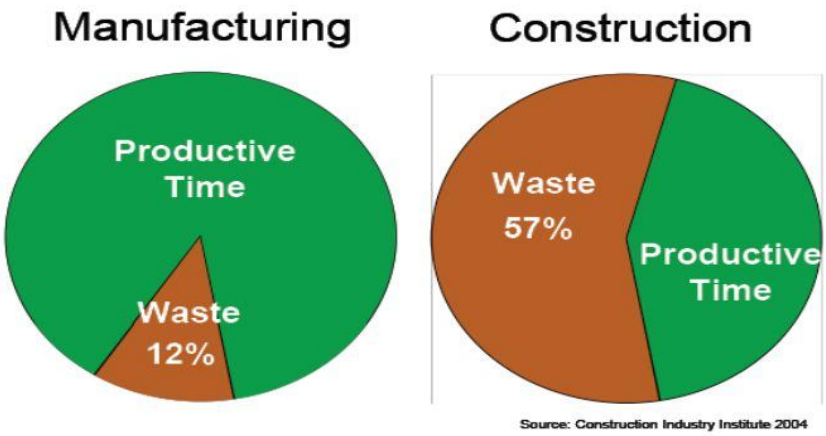


Figure 8 Waste in manufacturing and construction [construction industry institute, 2004]

During last decades, many research efforts have been done in order to classify construction waste according to different attributes such as kind, quantity, etc. In spite of different classifications, all of them follow the same basic concept. Excess materials, delays, rework and defects are those

waste commonly mentioned by researchers (Senaratne and Wijesiri, 2008). Although the term 'construction and demolition waste' has been defined as any kinds of solid waste generated during construction processes, Formoso et al. (2002) recommended broader definition of waste to include not only material waste but also waste generated in a construction project such as waiting times, transportation times, and etc. Actually, this issue of non-physical waste within construction processes, is the basis of waste concept from lean construction approach. Actually, these kinds of waste are those wastes that occurred during the construction processes. Koskela (1992) also states that a systematic attempt for identifying wastes in construction processes (flow wastes in lean thinking terms) has not been done by the construction management practitioners until lean construction concept was introduced. Innovative waste categorization, which is considered lean thinking concept.

Waste exists in different forms, including over-production, waiting, unnecessary movement, carrying unnecessary inventory, and rework (Womack & Jones, 2003) as shown in figure 9. Time studies and different process analysis techniques have been applied to systematically identify and quantify wastes during the construction process (Lee et al., 1999).

Waste involves anything that adds no value from the clients' perspective. The essential focus of lean is to provide a product that the client truly need through identification and removal of waste in process in a step by step approach. In other words, the focus of lean is more on value than cost, which seeks to improve value added activities whilst eliminating non-value added ones. Two kinds of activities were recognized by (Ohno, 1988): i) Value-Adding Activities; and ii) Non Value-Adding Activities. The latter are essentially wastes and ought to be removed from processes. However, Hines and Rich (1997) further observed three classifications of production activities and these include: a) Non-Value Adding Activities which are considered pure waste and unnecessary activities which ought to be totally eliminated; b) Necessary but Non-Value Adding Activities which involve operations that may be considered as waste yet are essential within the operating procedures. In order to eliminate them, some changes are required to enhance the standard operating procedures; and c) Value Adding Activities which include the change or transforming of raw materials or semi-finished products to finished products.

Recently, waste in construction has been a subject of interest for many researchers across the globe. Nonetheless, the focus has been on material waste, which tends to be one among the resources in construction process (Abdul Rahman et al., 2012). Tersine (2004) described waste as undesirable, money, time and other resources consuming activities which add no value to a product. For the most part, the idea of waste is specifically connected with the use of resources that add no value to the finished product. This is all that much not quite the same as the construction professionals' perspective of waste where waste is alluded to be material waste and there have not been any significant effort to separate activities of construction into value adding and non-value adding activities (Abdul Rahman et al., 2012).Waste is characterized in Ohno (1988) seven (7) types of waste: Overproduction, Time on hand (waiting), Transportation, Additional/Inappropriate Processing, Inventories, Movement and Making Defective Products. According to Tersine (2004), Waste in manufacturing and construction involves excesses in inventory, time overruns, cost of quality, absence of safety, rework, unnecessary transportation, queue time, long distances, setup, handling, movements, Inspections, expediting, poor decision or management strategies, requirements, among others. Also, according to Koskela et al. (2013), waste can be differentiated between operational and process waste. Movement and waiting can be waste of machines or people which are moving unnecessarily or being idle, and these are considered to be operational wastes. The other five (overproduction, transportation, additional processing, inventories and making defective products) are process waste.

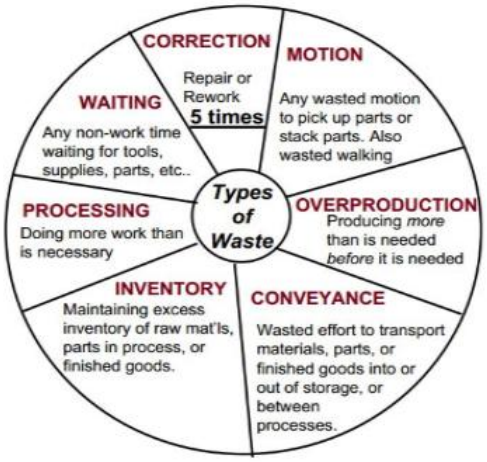


Figure 9 Ohono's seven types of waste [Ohno, 1988]

The seven types of waste was further explained by Abdul Rahman et al., (2012) as follows;

ii. Overproduction is identified with producing more than required or producing earlier than should be expected. This regularly results in quantity and quality issues; an organization realizes that it will lose various units along the process of production so delivers additional to verify that the client request is fulfilled. This may result in misuse of materials, worker hours or usage of equipment.

iii. Waiting is identified with idleness which is mostly caused by poor synchronization and material flow leveling, and pace of work by distinctive equipment or groups. Also, waiting occurs at whatever point products are not being processed or moving. The idleness is perhaps created during waiting for engineering, maintenance, raw materials, designing, quality assurance results, inspections, confirmation order, and so forth. Waste generated through waiting can be reduced drastically by connecting the processes together and sustaining the flow of the processes.

iii. Transportation (Material/Equipment Movement) has to do with the moving of materials or equipment within site where poor working environment layout or an absence of process flow makes numerous stops and starts in a cycle of production. The working environment of construction site can fundamentally be the major reason contributing to unnecessary transportation. Also, extreme handling, utilization of inadequate equipment or bad states of pathways can likewise precipitate this type of waste. It is worth noting that, every movement ought to have a reason since things being moved incur some kind of cost. Work process flow interruptions can significantly add to the costs of transportation. These wastes include; waste of worker's hours, waste of space on site, waste of energy, and the likelihood of waste of material during transportation. Proper re-laying out of the machines within an industrial facility from a functional to a cellular layout has been demonstrated to not just help reduce waste generated by transportation but as well reduce Work in Progress (WIP) and Waiting. Likewise this can be applied to the construction industry where appropriate plan for site layout would be able to minimize unnecessary material movement.

iv. Processing (Excessive Processing/Over Processing) occurs in situations where processing or conversion activity does not add value to the product or service from the client's perspective. This

is constantly created by the quality issue of the work done. The most evident example of over-processing is rework relating to surface finishes or works. This waste can likewise be avoided by changing the technology used for construction.

v. Inventory (Stock/Storage Waste) is identified with unnecessary or excessive inventories which prompt material waste (by losses because of insufficient stock conditions at site, robbery, deterioration, vandalism), and fiscal losses because of the capital being tied up. Excessive inventory is seen as waste since there is no value activity in stocking inventory. Moreover, inventory occupies space, adversely affects capital, and incurs costs, among others. Organizations often arrange more than needed to satisfy a request. The problems associated with inventory may be due to quality problems with the production processes and may likewise be as a result of inadequate resource planning or uncertainty on the quantity estimations.

vi. Movement (Motion) is identified with ergonomics and is seen in all instances involving stretching, bending, lifting, strolling and reaching. The waste generated by motion is concerned with the unproductive or unnecessary movements made by employees during work hours. This waste may be caused by poor work methods, lack of equipment, or poor work area arrangement. Also, a long distance which must be covered within a work site to perform or accomplish assignments is also considered waste of time and effort. Unnecessary movements may create or increase the level of injuries, accidents, and their related costs. Lean thinking seeks to minimize poor housekeeping, poor work area organization, poor layout of machinery, and poor or inconsistent work methods. Hence, when there is a proper work area layout, unnecessary or unproductive motion of workers would be minimized, and this would lead to costs saving. Therefore, jobs or occupations involving unnecessary movements ought to be examined and redesigned to minimize motion and its associated costs.

vii. Making Defective Products (Rejects/Unacceptable/Unnecessary Work) happen when the finished or half processed products are not up to the quality requirements. This is the common waste produced by the construction industry where segments or products made are not up to specifications. Defects may prompt rework or the use of poor or unnecessary materials to the building; for instance, extreme thickness of plastering works. The cost of product considered as

defective is the same as it does to deliver a prize product. Other than the losses, there are numerous different costs connected with rejects that make this an especially imperative classification of waste to minimize or eliminate. Defects can happen through an extensive variety of reasons, for example, poor specification and design, inadequate planning and control, inadequate qualification of the project/work team, poor integration of design and production, just to mention a few. New methods to handle defects must be used and checked (Alireza and Sorooshian, 2014).

In addition to Ohno's seven types of wastes, various analysts have presented the eighth and other wastes. For instance, Macomber and Howell (2004) identified several waste which can extensively be classified as: inability to utilize individuals' abilities, skills and capacities; behavioral waste; information waste; and waste of good ideas. Also, Womack and Jones (2003) have included the eighth waste, which is the design of goods and services which do not satisfy the needs of the end user. More also, Burton and Boeder (2003) have included waste of human potential as the eighth type of waste. Waste of human potential is identified with the failure in fully using the skills of individuals. Besides Ohno's seven types of wastes, one of the important wastes mostly observed in construction according to Koskela et al., (2013), is the making-do. Making-do waste is related to a circumstance where a task is begun without all its standard inputs or a task is preceded before all preconditions or requirements or data are ready. However, Ohno's seven type of wastes will be considered for this research as other wastes (NVA) classification.

2.9 Literature Summary and Gap Identification

As part of fulfilling the requirements of this thesis objectives, different literatures and journals were reviewed. History of lean production, the diffusion of lean ideas, lean in construction, tools and techniques of lean construction and waste in lean construction were also briefly discussed in this chapter.

During last decades, various methods are utilized in order to reduce construction waste and its effects. One of innovative approaches in this regard is "Lean Construction", which was introduced to construction industry in 1990s based on a successful manufacturing theory, i.e. lean production. In general, project managers interpret waste as physical construction waste, which dominantly

includes material losses (Koskela, 1992). In addition to stressing on the physical waste, lean thinking specifically pay lots of attentions to the waste produced over a construction process i.e. reducing the time from start to delivery by eliminating the source of waste in the work flow is one of the basic concepts of lean enterprise. Waiting time, non-value adding works and material transportations are categorized in this group. In construction, lean techniques are used to reduce waste and increase productivity.

In Ethiopia different thesis were done focused on construction material wastes both on undergraduate and postgraduate level by; Getachew Araya (2009), Mulualem, Negatu and Tedla (2012), Esikedar Girma (2016), Addise, (2005), Asmara Seyoum (2015) and so many more. This indicates that focuse has been given only to construction material (physical) wastes. Nonetheless Formoso et al. (2002) recommended broader definition of waste to include not only material waste but also waste generated in a construction project such as waiting times, transportation times, and etc. This issue (non-physical waste within construction processes), is the basis of waste concept from lean construction approach. Thus this research is based on a thorough identification and categorization of the construction wastes based lean construction systems on selected building construction sites and making cases for and how these lean ways of wastes categorization could take hold in the Ethiopian Construction Industry.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter describes the overall plan for original data collection, construction company selection for case studies, data analysis and methods for fulfilling objectives of the research stated in Chapter1.

3.1 General concept

Construction site activities has been categorized in several ways. Traditionally construction site activities has been categorized as direct, support and delay. Using lean concepts as the foundation, the nature of VA actions and waste can be defied and categorized. Ohno (1988) subcategorizes waste into non-value adding but required (NVAR) Type I muda (waste), and non-value adding (NVA) Type II muda (waste). In addition CII (2004) revised Ohno's activity categories. Furthermore CII (2010), further explained activity categories. However for this research purpose CII's 2004 category definition has been used. Table 1 shows activity category definition comparison.

Traditional Construction Activity Category	**CII's 2004 Category**		**CII's 2010 Category**
Direct	VA	Value adding	Tool Time
Support	NVAR	Material Positioning	Preparatory – work
		In-Process Inspections	Tools and equipment
		Temporary Work and Support Activities (TWSA)	Material Handling
Delay	NVA	Overproduction	Waiting
		Waiting	
		Transport	
		Extra-processing	Travel
		Inventory	Personal
		Motion	
		Defect	

Table 1Activity category comparison

3.2 Categories of work

Inefficiencies are classified as one of three types: inefficiency due to waste (NVA activities), inefficiency due to work that does not directly contribute value (NVAR activities) and inefficiency due to poorly designed work processes (ineffective VA activities). After definitions for VA, NVAR and NVA actions were created, the research focused on procedures for collecting and analyzing these data for typical construction tasks. The definitions for VA, NVAR and NVA is based on James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004).

3.2.1 VA definition

According to Walbridge-Aldinger (2000) strict definition for VA activities as "any activity that changes the shape, form, or function of materials or information to meet customer's needs" This definition excludes common construction work such as material handling, inspection or temporary structures. Another less precise way of thinking about VA activities is that they are those activities that the client is actually interested in purchasing. For example, one could say that the client is interested in purchasing a steam line for a power plant, but not the temporary support or testing activities that are needed to produce a finished pipeline. A VA action in this process is the physical welding of the pipe spools into their final position. This strict definition for VA activities has been adopted in this research to categorize waste. James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004).

3.2.2 NVAR Definition

This category can be separated into three subcategories that are required for construction operations, yet have no permanent effect on the finished product. These subcategories include material positioning, in-process inspection, and temporary work and support activities (TWSA) James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004). However this definitions doesn't usually apply to the Ethiopian construction industry case.

3.2.2.1 Material Positioning.

This subcategory includes all activities that involve the movement of a structural steel member into its final position. For example, placing reinforcement bar to its final position in the structure is a required action, but it does not actually change the physical characteristic of the finished product. The structure is physically changed only when bars are tied with steel wire. (Note: one must be careful when labeling an activity as material positioning. Material positioning does not include moving a rebar from the laydown yard to a staging area. This action should be labeled as "transport," which is an NVA activity James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004).

3.2.2.2 In-Process Inspections.

This subcategory includes actions such as the leveling, plumbing and/or final field measurements of installed material. It also includes in-process or production weld inspections that are required in accordance with individual project specifications. This subcategory accounts for current construction requirements of inspecting ongoing and finished products to ensure quality to the customer. For example, continually plumbing and leveling the structure as steel members are erected would fall under this subcategory. James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004).

3.2.2.3 Temporary Work and Support Activities (TWSA).

This subcategory includes all actions that must occur while activity-specific equipment is being used to erect and secure a member into its final position. Attaching or adjusting rigging, setting up temporary supports or wrapping a steel member with the hoist line to lift it into its final position would fall under the TWSA subcategory. It also includes those actions needed to ensure that equipment in use during the activity continues to work in the most optimal manner. Each NVAR activity provides an opportunity to redesign the process to eliminate or reduce the NVAR component in a cycle. For example, one could redesign a building to allow for multiple repetitions and reuses of formwork, thereby reducing the work content of the formwork activity. Alternatively, one could redesign the structure to use precast foundation elements, thereby

eliminating the need for formwork altogether James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004). For this research purpose formwork activities are considered as TWSA assuming that it's not a paid item.

3.2.3 NVA (Waste Definitions)

Waste reduction and elimination is one of the core principles of lean production, and although it is not the only benefit of lean implementation, it does provide a logical starting point. The potential cost and time savings achieved by eliminating or reducing NVA activities are significant. Studies show that only 3 to 20 percent of tasks add value (Ciampa 1991. Womack and Jones (1996) define waste as "any human activity that absorbs resources but creates no value." The definition developed by Walbridge-Aldinger (2000) better conforms to construction production; waste is defined as "anything that takes time, resources or space but does not add value to the product or service delivered to the customer." To develop the construction production value stream, Ohno's concepts of production was modified by James E. Diekmann, Mark Krewedl, Joshua Balonick, Travis Stewart, and Spencer Won, (2004) to more closely conform with construction production as follows

- **Overproduction** - Products being produced in excess quantities or products being made before customers need them. This implies that production on a late-start schedule is the ideal. Indeed, from the client's viewpoint, if a late-start schedule could be guaranteed in the face of weather, supplier schedules and other uncertainties, a late-start schedule would minimize WIP and cash flow requirements.
- **Waiting-** Products, equipment or people that must wait because of poor scheduling, production control or unbalanced crew size. Changing work tasks in the course of a typical construction sequence make establishing a proper crew composition difficult.
- **Transport-**Unnecessary movement of materials. Material handling and transport necessitated by the relocation of work are unavoidable in construction. This type of waste includes excessive, multiple and suboptimal movements of material.
- **Extra Processing**-Rework, re-handling or storage that is caused by defects in design, fabrication or construction activities. This type of waste occurs within crews.

- **Inventory**-Extra raw or fabricated materials, excess construction equipment.
- **Motion**-Extra movement by employees or movement of equipment caused by inefficient layout, remote lay-down areas or improper work sequences.
- **Defects**-Errors or deficiencies in finished products that require a crew to return to a work item or require a follow-up crew to perform added work (punch list items). This type of waste occurs between crews.

3.3 Data collection procedure

A total of six case studies at six construction sites but at five construction companies were conducted as part of this research. Rebar work for column and slab, concrete work for slab, beam and column and formwork for column are the major activities observed while conducting the case studies. Two cases focuses on rebar work for slab, two cases focuses on concrete work for slab and two cases focuses on column work which includes rebar, formwork and concrete work. Two different methods were used to gather data. The first method video data collection required digital camera to record each crew's movements. The second method questionnaire to identify the basic understandings of project managers towards construction wastes on selected sites. Video data collection required to be entered into spreadsheets so that the necessary tabular results could be generated using excels for each job. Table 1 is an example of one of the data sheets used for rebar work.

3.3.1 Video Data Collection

Video data collection required the researcher to operate a digital video camera (Nikon COOLPIX S8200 (wide 14x)). The digital video camera was positioned to view the activity area at right angles to provide "depth" in directions being viewed. The researcher received permission letter from all construction sites to record the entire workers activities, however Site-specific information have been removed to prevent disclosure of proprietary information,

Viewing the videos several times allowed one to record data on each of the observed crew members. After viewing the videos several times, the researcher used stopwatch and a data sheets as shown in Table 2. Data was recorded as the activities occurred. Each time a new task was started,

an entry was made on the data sheet. For example an entry might indicate that a worker was positioning re-bar for slab .The next entry might indicate that the worker was "waiting" until the crane lowers rebar for the next section to be placed. The elapsed time for each task was recorded, as well as the observer's judgment regarding whether the task was "value-adding" to the process. Worker in a crew is represented in the first column of the data sheet. Names for each worker were determined by the type of activities performed. The second column describes the specific building component that the worker was working on at a specific point in an observation period. The third column indicates the activity observed for that specific time period. The forth column shows the duration of time spent on that activity. The fifth column specifies whether an activity is VA, NVAR or NVA. The sixth column provides for a further subcategorization of each activity into one of the seven wastes or one of the three subcategories of NVAR activities.

Table 2 Data analyzing sheet

Name of the company , A						
Field classification sheet 1				***Case study No 1***		
Person or Equipment entire group cycle time				***Date 2/29/17 (Day One)***		
No	**Worker**	**Member classification**	**Activity**	**Time at activity**	**Activity classification**	***Waste classification***
1	Re-bar worker one	Rebar for slab	Adjusting rebar position	00:00:21	NVAR	Material positioning
2	Re-bar worker one	Rebar for slab	Checking rebar alignment	00:01:20	NVAR	In-process Inspection
3	Re-bar worker one	Rebar for slab	Checking rebar alignment	00:01:53	NVAR	In-process Inspection
4	Re-bar worker one	Rebar for slab	Cleaning formwork surface	00:01:49	NVAR	TWSA
5	Re-bar worker one	Rebar for slab	Rework	00:00:59	NVA	Extra processing
6	Re-bar worker one	Rebar for slab	Cutting and tying the steel wire	00:00:22	VA	Value adding
7	Re-bar worker one	Rebar for slab	Cutting and tying the steel wire	00:00:23	VA	Value adding
8	Re-bar worker one	Rebar for slab	Measuring and marking	00:00:10	NVAR	In-process inspection
9	Re-bar worker one	Rebar for slab	Rework	00:01:05	NVA	Extra processing
10	Re-bar worker one	Rebar for slab	Rework	00:00:10	NVA	Extra processing
11	Re-bar worker one	Rebar for slab	Rework	00:00:33	NVA	Extra processing
12	Re-bar worker one	Rebar for slab	Talking while waiting	00:00:41	NVA	Waiting
13	Re-bar worker one	Rebar for slab	Unnecessary Transporting	00:00:26	NVA	Transporting
14	Re-bar worker one	Rebar for slab	Walking	00:00:10	NVA	Motion

3.3.2 Questionnaire

Questionnaires were distributed to project managers among construction sites where the case studies were conducted. The main purpose of distributing the questionnaires was in order to know the basic understanding of the project managers towards construction wastes and non -physical wastes (lean ways).

The advantage and disadvantage of different data collection methods are discussed on Table 3.

Table 3 Advantages and disadvantages of different data collection methods.

Data collection method	Advantages	Disadvantages
Video data collection	▪ Allow more detail review of the work cycle.	▪ Limited by camera's views of the cycle ▪ Longer period of time required for analyzing each member of a crew ▪ Real workers performance can possibly be biased
Questionnaire	▪ Simple to analyze	▪ Analysis is based on opinions of a single key professional at each company (Either at project level).

3.4 Construction company selection for the case studies

The method used for selecting construction companies for the case studies is based on purposive sampling. Construction companies were basically selected based on the methodologies and machineries used for the selected activities. Further explanation for the selection criteria are as follows;

- According Ohno (1988) unnecessary inventory is a waste (NVA). To ascertain two companies were selected, one company who has a workshop for bending and cutting reinforcement bars and delivered to site when needed in required amount and one company where reinforcement bars are cut and bend on site and delivered to actual construction site.
- According to Rahman et al. (2012), wastes like waiting time, transporting and extra processing can be avoided by changing the technology used for construction. To demonstrate this point two companies were selected for concrete work (slab) based

different kind of machineries and technologies used by the companies while placing concrete for slab.

- According to Walbridge-Aldinger (2000), NVAR activities like temporary work and Support Activities (TWSA) can be optimized by using modular techniques and prefabricated elements, in addition each NVAR activity provides an opportunity to redesign the process to eliminate or reduce the NVAR component in a cycle.to verify this point one company who uses a modular formwork (column) that are assembled on site and on the other hand one company who uses formwork (column) that are prepared on site using plywood were selected.

Furthermore the all the companies selected for the case studies specifically meet the following criteria;

- Grade one contractors (GC) assuming that they all use the necessary techniques and machineries for the selected activities.
- More than ten years of experience on building construction
- Minimum three ongoing construction sites
- Willingness of the companies and the workers to be video recorded while engaged on selected activities

CHAPTER FOUR

ANALYSIS AND DISCUSSION

The Analysis part is categorized into three major parts. The first category focuses on identifying and categorizing of each crew member's activities as well as waste classification on selected activities and construction sites based on lean concepts. The second category focuses on comparing the different techniques and mechanisms used while performing the same task on selected companies, to see if different mechanisms used has an impact on each crew's activities while performing (value adding (VA), non-value adding but required (NVAR), and non-value adding (VA) activities. The third category focuses on survey on perception of construction waste by the project managers where the case studies were conducted.

4.1 Case studies

The six case studies focus on three trends: the reinforcement bar for slab work process, the concrete work for slab and column work process. The first two successive case studies focus on reinforcement bar for slab work process, the first company has its own workshop where the reinforcement bars are cut and bend offsite and delivered to the construction site, on the other hand the second company doesn't have its own workshop rather reinforcement bars are cut and bend on site and delivered to the actual construction site by the workers. The second two consecutive case studies focus on concrete work for slab process, the first company used ready mix concrete and trailer pumps(small general pump) for placing concrete, on the other hand the second company used power boom (remote pedestal booms) for placing concrete, in addition both companies used water-reducing, high range admixture. The last two consecutive case studies focus on column work process, the column has three trends i.e. rebar work process, formwork work process and concrete work process, the first company used plywood for formwork preparation and daily labors were used as part of placing concrete for columns, while the second company used modular formworks that are assembled on site and concrete for column was placed using power boom (remote pedestal booms).

The following subsections provide a brief description of the case study projects and the cycle(s) observed during the observation period. Site-specific information have been removed to prevent disclosure of proprietary information. A partial analysis of each case study is presented in Appendices.

4.1.1 Case study No.1 and No.2

Reinforcement bar work for slab

The major activities and categories of rebar work for slab are shown on Table 4.

Table 4 Categories and activities of rebar work (slab).

Categories of work	Activities
VA	
Value adding	Cutting and tying steel wire
	Providing spacing bar
NVAR	
Material positioning	Positioning bottom bar
	Positioning top bar
	Adjusting rebar position
In-process Inspection	Checking rebar alignment
	Inspection
	Measuring and marking
NVA	
Waiting	Doing noting while waiting, talking
Transporting	Unnecessary transportation
Extra processing	Rework
Inventory	Sorting and categorizing bar size
Motion	Walking, unnecessary movement
Defect	Defect(defective work)

4.1.1.1 Case study No.1

The project was for one of Addis Ababa's sub-city office buildings. The project had three different phases, the case study focused in one of G+ 7 building. The total area of the building is 627.81 m^2. Rebar work by nature is highly repetitive. The researcher observed the rebar work (slab) associated with 145.69 m^2.Video data collection was used along with data sheet to observe each crew members' activities. Eight workers were engaged for four days in order to place 2,552.34 Kg (Ø10)

Bar in 145.69 m^2 area.

Reinforcement bars are cut and bend on construction site and delivered to actual working site using both tower crane and rebar workers in addition reinforcement bars were purchased and delivered to site on abandoned manner as a result some of the rebar workers spend there working time by sorting and categorizing reinforcement bars according to their size before positioning reinforcement bars to the actual working site.

The summary of each crew member's activity along with waste classification and actual time spent on VA, NVAR and NVA activities presented on Table 5 .In addition the summary of the entire crew result on percentile are shown on Table 6 along with chart 1.

Table 5 Typical result for rebar crew completing rebar work for slab section.

Typical result for rebar crew completing rebar work for slab section									
Activity classification	***Waste classification***	***Worker No 1***	***Worker No2***	***Worker No 3***	***Worker No4***	***Worker No 5***	***Worker No 6***	***Worker No 7***	***Worker No 8***
VA	-	02:34:45	02:22:09	01:40:48	03:23:09	03:51:51	00:49:06	01:15:28	00:31:01
VA Total		**02:34:45**	**02:22:09**	**01:40:48**	**03:23:09**	**03:51:51**	**00:49:06**	**01:15:28**	**00:31:01**
NVAR	***In-process inspection***	01:02:11	00:10:14	00:06:18	00:57:48	00:15:51	00:27:52	00:53:58	00:06:25
	Material positioning	01:32:58	01:04:28	00:56:14	02:09:14	02:00:24	00:37:38	00:52:04	00:15:43
NVAR Total		**02:35:09**	**01:14:42**	**01:02:32**	**03:07:02**	**02:16:15**	**01:05:30**	**01:46:02**	**00:22:08**
NVA	***Waiting***	01:54:45	00:47:35	01:00:25	01:19:56	0:57:18	00:29:00	00:47:08	00:07:07
	Transport	01:36:12	00:06:18	00:40:05	01:30:57	01:22:37	00:14:28	00:26:53	00:12:10
	Extra processing	00:22:06	00:28:50	00:20:30	00:44:50	00:45:21	00:09:06	00:14:50	00:15:01
	Inventory	00:38:00	00:02:48	00:14:32	01:43:37	01:08:24	00:00:00	00:50:35	00:00:00
	Motion	00:42:33	00:17:10	00:33:24	00:25:31	01:23:53	00:13:08	00:34:22	00:18:21
	Defect	00:02:52	00:00:00	00:00:00	0:08:38	00:08:34	00:00:00	00:00:20	00:00:00
NVA Total		**04:16:28**	**01:42:41**	**02:48:56**	**05:53:29**	**05:46:07**	**01:05:42**	**02:54:08**	**00:52:39**
Grand Total		**09:26:22**	**05:19:32**	**05:32:16**	**12:23:40**	**11:54:13**	**03:00:18**	**05:55:38**	**01:45:48**

Table 6 Typical result for rebar crew completing rebar work for slab section in %.

Activity classification	*Waste classification*	*Typical result for rebar crew completing rebar work for slab section in %*								
		Work No.1	*Work No.2*	*Work No. 3*	*Work No.4*	*Work No.5*	*Work No.6*	*Work No.7*	*Work No.8*	*Crew%*
VA	-	27.32%	44.49%	30.34%	27.32%	32.46%	27.23%	21.22%	29.32%	29.79%
VA Total		**27.32%**	**44.49%**	**30.34%**	**27.32%**	**32.46%**	**27.23%**	**21.22%**	**29.32%**	**29.79%**
NVAR	*In- process inspection*	10.99%	3.20%	1.90%	7.77%	2.22%	15.50%	15.18%	6.06%	7.25%
	Material positioning	16.41%	20.18%	16.92%	17.38%	16.86%	20.83%	14.64%	14.86%	17.14%
NVAR Total		**27.40%**	**23.38%**	**18.82%**	**25.15%**	**19.08%**	**36.33%**	**29.82%**	**20.92%**	**24.39%**
NVA (waste)	*Waiting*	20.26%	14.89%	18.18%	10.75%	8.02%	16.08%	13.25%	6.73%	13.36%
	Transport	6.39%	1.97%	12.06%	12.23%	11.57%	8.02%	7.56%	11.50%	9.33%
	Extra processing	3.90%	9.02%	6.18%	6.03%	6.35%	5.04%	4.17%	14.19%	6.05%
	Inventory	6.71%	0.88%	4.37%	13.93%	9.58%	0.00%	14.22%	0.00%	8.38%
	Motion	7.51%	5.37%	10.05%	3.43%	11.74%	7.30%	9.67%	17.34%	8.09%
	Defect	0.51%	0.00%	0.00%	1.16%	1.20%	0.00%	0.09%	0.00%	0.61%
NVA Total		**45.28%**	**32.13%**	**50.84%**	**47.53%**	**48.46%**	**36.44%**	**48.96%**	**49.76%**	**45.82%**
Grand total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

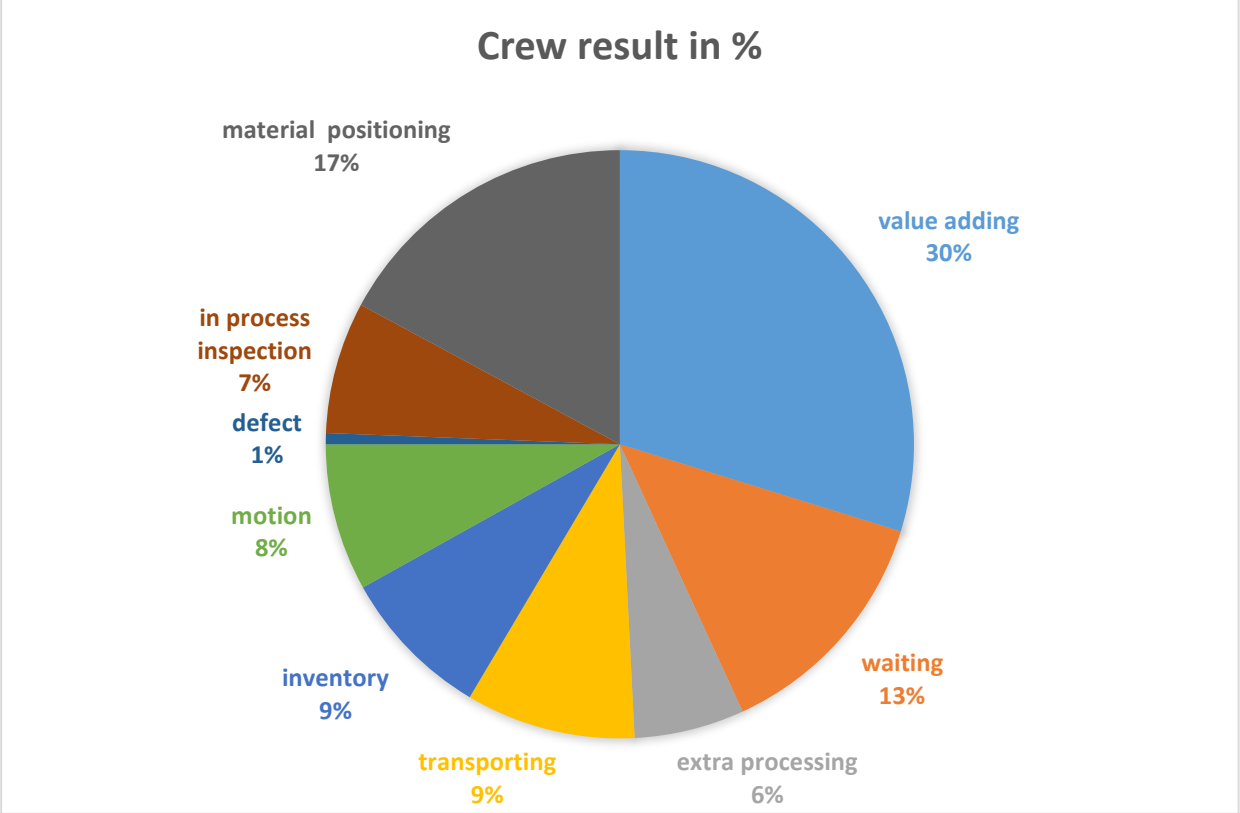


Chart 1 *Typical result for rebar crew completing rebar work for slab section.*

The weighted average crew result shows that only 29.79% of the working hours per slab section was spent on value adding (VA) activities, 24.39% of the working hours per slab section was spent on NVAR and the rest 45.82% was spent on NVA activities. 29.79% of the VA was spent on cutting and tying steel wire and providing spacer bars. Among the 45.82% of the NVA activities 13.36% of the working hours per slab section was spent on waiting for confirmation order, inspections and waiting for delivery of reinforcement bar to the site, this also takes the biggest share among the others.in addition 9.33% of the NVA was spent on unnecessary transportation of heavy reinforcement bars while it could easily have been transported by heavy lifting tower crane and moving of materials on poor working condition. Another 8.38% of NVA was spent on trying to sort and categorize excess amount of reinforcement bars (inventory) stored on the construction site which in addition hampered the movement of the workers while transporting reinforcement bars. Additional 8.09% of the NVA was spent on unnecessary movement of the workers which includes walking and talking to colleagues and any unnecessary movement of the workers due to poor work area arrangement. In addition 6.05% of the NVA working hours per slab section was spent on extra processing which includes rework and spending more time on a given activity than required. Among the NVAR activities material positioning which includes positioning bottom and top bar and adjusting rebar position takes 17.14%, and it also takes the biggest share among the NVAR activities. In-process inspection (NVAR) which includes checking rebar alignment, inspection and measuring and marking rebar takes the rest 7.25%.

4.1.1.2 Case study No.2

The project was a 1B +G+8 building for an Office purpose. The total area of the building is 504.98 m^2.The researcher observed the rebar work for slab associated with 98.45 m^2.Video data collection was used along with data sheet to observe each crew members' activities. Eight workers were involved for two days in order to place 2,320.06 Kg (Ø10) bar in 98.45 m^2 area.

Reinforcement bars are cut and bend on the company's own workshop located outside the construction site and delivered to actual working site when needed in the required amount. After delivered to construction site, reinforcement bars are delivered to the actual working site using both tower crane and the rebar workers.

The summary of each crew member's activity along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 7.In addition the summary of the entire crew result on percentile are shown on Table 8 along with chart 2.

Table 7Typical result for rebar crew completing rebar work for slab section.

Typical result for rebar crew completing rebar work for slab section									
Activity classification	***Waste classification***	***Worker No 1***	***Worker No2***	***Worker No 3***	***Worker No4***	***Worker No 5***	***Worker No 6***	***Worker No 7***	***Worker No 8***
VA	**-**	01:32:55	01:54:18	01:40:56	01:04:15	01:20:28	01:31:15	01:35:42	01:32:27
VA Total		**01:32:55**	**01:54:18**	**01:40:56**	**01:04:15**	**01:20:28**	**01:31:15**	**01:35:42**	**01:32:27**
NVAR	***In-process inspection***	00:16:14	00:07:59	00:04:33	00:14:23	00:02:00	00:05:48	00:16:27	0:00:59
	Material positioning	00:25:25	00:21:17	00:32:19	00:46:47	00:50:45	00:43:44	00:31:53	00:43:09
NVAR Total		**00:41:39**	**00:29:16**	**00:36:52**	**01:01:10**	**00:52:45**	**00:49:32**	**00:48:20**	**00:44:08**
NVA	***Waiting***	00:14:58	00:20:01	00:17:55	00:28:59	00:12:07	00:14:08	00:14:18	00:16:27
	Transport	00:35:45	00:20:40	00:26:51	00:25:05	00:15:05	00:18:19	00:18:37	00:17:26
	Extra processing	00:11:20	00:05:53	00:03:08	00:06:35	00:13:05	00:02:49	00:03:37	00:16:21
	Inventory	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	0:00:00
	Motion	00:13:52	00:10:30	00:06:45	00:10:24	00:07:59	00:13:39	00:03:51	00:05:53
	Defect	00:00:49	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:03:36	00:04:00
NVA Total		**01:16:44**	**00:57:04**	**00:54:39**	**01:11:03**	**00:48:16**	**00:48:55**	**00:43:59**	**01:00:07**
Grand Total		**03:31:18**	**03:20:38**	**03:12:27**	**03:16:28**	**03:01:29**	**03:09:42**	**03:08:01**	**03:16:42**

Table 8Typical result for rebar crew completing rebar work for slab section in %.

Activity classification	Waste classification	Typical result for rebar crew completing rebar work for slab section in %								
		Work No.1	Work No.2	Work No. 3	Work No.4	Work No.5	Work No.6	Work No.7	Work No.8	Crew%
VA	-	43.97%	56.97%	52.45%	32.70%	44.34%	48.10%	50.90%	47.00%	47.04%
VA Total		**43.97%**	**56.97%**	**52.45%**	**32.70%**	**44.34%**	**48.10%**	**50.90%**	**47.00%**	**47.04%**
NVAR	In- process inspection	7.68%	3.98%	2.70%	7.32%	1.10%	3.06%	8.75%	0.50%	4.39%
	Material positioning	12.04%	10.61%	16.79%	23.82%	27.96%	23.05%	16.96%	21.94%	18.97%
NVAR Total		**19.72%**	**14.59%**	**19.49**	**31.14%**	**29.06%**	**26.11%**	**25.71%**	**22.44%**	**23.36**
NVA (waste)	Waiting	7.08%	9.98%	8.97%	14.75%	6.68%	7.45%	7.61%	8.36%	8.92%
	Transport	16.92%	10.30%	13.95%	12.77%	8.31%	9.66%	9.90%	8.86%	11.42%
	Extra processing	5.36%	2.93%	1.63%	3.35%	7.21%	1.48%	1.92%	8.32%	4.04%
	Inventory	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Motion	6.56%	5.23%	3.51%	5.29%	4.40%	7.20%	2.05%	2.99%	4.68%
	Defect	0.39%	0.00%	0.00%	0.00%	0.00%	0.00%	1.91%	2.03%	0.54%
NVA Total		**36.31%**	**28.44%**	**28.06%**	**36.16%**	**26.60%**	**25.79%**	**23.39%**	**30.56%**	**29.60%**
Grand total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

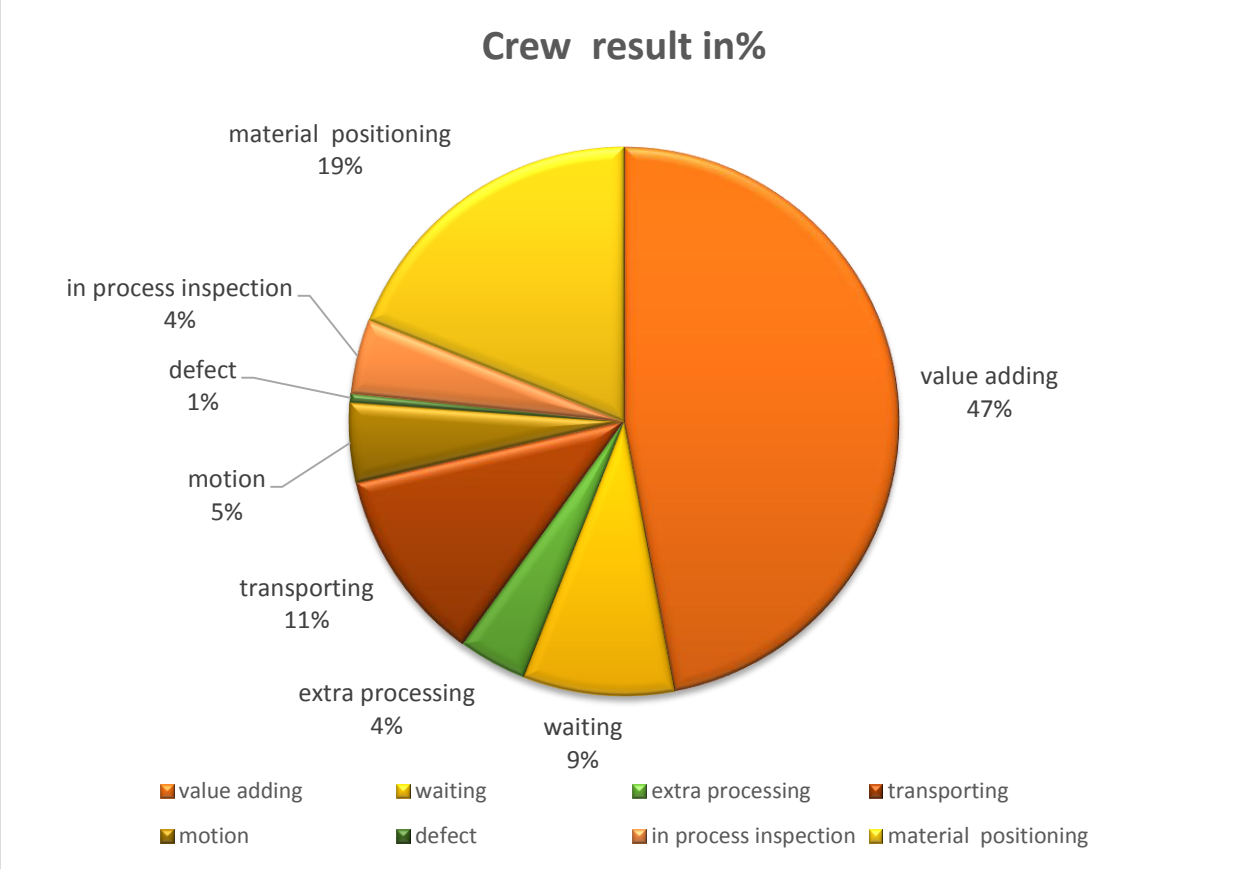


Chart 2 Typical result for rebar crew completing rebar work for slab section.

The weighted average crew result shows that only 47.04% of the working hours per slab section was spent on value adding VA activities, 23.36% of the working hours was spent on NVAR and the rest 29.59% was spent on NVA activities. 47.04% of the VA was spent on cutting and tying steel wire and providing spacer bars. Amongst the 29.59% of the NVA activities 8.92% was spent on waiting for confirmation order, inspection and waiting for delivery of materials, this also takes the biggest share among the others. 11.42% of the NVA was spent on unnecessary transportation of heavy reinforcement bars by the workers. Another 4.68% of the crews' working hour was spent on unnecessary movement of the workers which includes walking and talking to colleagues, and any unnecessary movement made by workers. In addition 4.04% of NVA was spent on extra processing which includes rework and spending more time on a given activity than required. Among NVAR activities material positioning which includes positioning bottom and top bar and adjusting rebar position takes 18.97%, and it also takes the biggest share among the NVAR activities. The rest NVAR was spent on in-process inspection which includes checking rebar alignment, inspection and measuring and marking takes only 4.39% of the working time.

4.1.1.3 Comparison of rebar cases

Generally both individual and crew result for rebar work at case study No.2 was better in terms of executing value adding activities in the work process. Rebar crew at case study No.2 performed 17% more while accomplishment value adding activities. In addition the company saved 8% of workers time spent on arranging and categorizing reinforcement bars brought to site in abandoned manner by separating the rebar bending and cutting place from the actual construction site, associated to this waste that emanates out of motion was less in the construction site because no excess amount of rebar was stored on site that can actually hamper the free movement of the workers. In Both companies waiting time (waiting for confirmation order, inspection and delivery of materials) takes significant amount of time, this shows an interruption of flow in the work process. Unnecessary transportation of heavy reinforcement bars from one side to other side also takes considerable amount of time on both construction sites, in addition tower cranes were not transporting construction materials efficiently at both sites especially at case study No.2. Time spent on rework at case study No.1 was 2% more than on case study No.2. In addition Time spent on NVAR at case study No.1 was 1% more than on case study No.2.

4.1.2 Case study No.3 and No.4

Concrete work for slab

The major categories and activities of concrete work are shown on Table 9.

Table 9 Categories and activities of concrete work (slab).

Categories of work	Activities
VA	
Value adding	Placing concrete
	Vibrating concrete
	Finishing concrete
NVAR	
In-process Inspection	Checking and measuring depth of concrete
Material positioning	Positioning and fixing concrete pump position
NVA	
Waiting	Doing noting while waiting for concrete truck, talking
Transporting	Unnecessary transportation
Extra processing	Rework
Motion	Walking, unnecessary movement
Defect	Defective work

4.1.2.1 Case study No.3

The project was in Addis Ababa University main campus. The project has five ongoing buildings for different purposes. The case study focused in one of the buildings being constructed for students' laboratory. It's a 3B+G+5 building with total area of 457.15m^2.The researcher observed concrete for slab work related with 106.06 m^2.Video data collection was used along with data sheet to observe each crew members' activities. The company used ready mix concrete delivered on site by mixing trucks and are placed trough trailer pumps (small general pumps).

There were 29 workers for placing 82 .29m^3 concrete in 457.15m^2 area. Among the 29 workers 9 were carrying concrete pipes hoses attached to the end and placing concrete, two crew each having

8 and 6 workers respectively were placing concrete using shovel, in addition 6 masons were vibrating and finishing concrete. Basically each crew member except the masons who were vibrating and finishing concrete were doing the same thing. The researcher observed concrete work only associated with17.3m^3 in 106.06m^2 area. The summary of concrete placing crew along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 10 and Table 11.The summary of concrete transporting crew along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 12. The summary of concrete vibrating and finishing crew (mason) along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 13 and Table 14 shows Masons' crew result on percentile. Finally the summary of the entire crew result on percentile are shown on Table 15.

Table 10Typical result for Concrete placing crew (1) completing placing for slab section.

Typical result for Concrete placing crew (1) completing placing for slab section			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	-	00:30:11	27.35%
VA Total		**00:30:11**	**27.35%**
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	01:12:39	65.83%
	Motion	00:07:32	6.82%
NVA Total		**01:20:11**	**72.65%**
Grand Total		**01:50:22**	**100%**

Concrete placing crew No.1 spent only 27.35% of the working hours per slab section on value adding activities i.e. by placing concrete using shovels while 72.65% of the working hours in slab section was spent on waiting (NVA) until concrete was transported through concrete pipes by the pump and until concrete pipe position was adjusted and the rest 6.82% of the working hours in a slab section was spent on unnecessary movement of the workers (dancing and wrestling).

Table 11Typical result for Concrete placing crew (2) completing placing for slab section

Typical result for Concrete placing crew (2) completing placing for slab section			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	-	00:41:28	37.48%
VA Total		**00:41:28**	**37.48%**
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	01:05:26	59.14%
	Motion	00:03:44	3.38%
NVA Total		**01:09:10**	**62.52%**
Grand Total		**01:50:38**	**100%**

The concrete placing crew No.2 spent only 37.48% of the working hours in a slab section on value adding activities by placing concrete using shovels while 62.52% was spent on waiting until concrete was transported through concrete pipes by the pump and until concrete pipe position was adjusted and the rest 3.38% was spent on unnecessary movement of the workers (dancing and wrestling).

Table 12Typical result for Concrete transporting crew completing transporting for slab section.

Typical result for Concrete transporting crew completing transporting for slab section			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	-	00:00:00	0.00%
VA Total		**00:00:00**	**0.00%**
NVAR	*Material positioning*	00:19:45	17.57%
NVAR Total		**00:19:45**	**17.57%**
NVA	*Waiting*	00:31:24	27.94%
	Transport	01:01:14	54.49%
NVA Total		**01:32:38**	**82.43%**
Grand Total		**01:52:23**	**100%**

The transporting crew on the other hand spent 54.49% of the working hours per slab section on unnecessary transportation of concrete by carrying heavy weighing concrete pipe hoses attached to the end all the way. Another 17.57% was spent on trying to adjust concrete placing pipe position

which is NVAR activity while the rest 27.94 % was spent on waiting until an empty concrete mixing truck was replaced by another loaded mixing trucks.

Table 13Typical result for a mason crew completing vibrating and finishing concrete for slab section.

Typical result for a mason crew completing vibrating and finishing concrete for slab section							
Activity classification	**Waste classification**	**Mason 1**	**Mason 2**	**Mason 3**	**Mason 4**	**Mason 5**	**Mason 6**
VA	**-**	00:46:25	00:30:53	00:40:27	00:25:27	00:33:19	00:00:00
VA Total		00:46:25	00:30:53	00:40:27	00:25:27	00:33:19	00:00:00
NVAR	**In-process inspection**	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:26:57
	Material positioning	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
NVAR Total		00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:26:57
NVA	**Waiting**	00:44:45	00:53:35	00:52:31	01:04:08	01:05:55	01:21:58
	Extra processing	00:11:10	00:08:14	00:06:00	00:00:00	00:00:00	00:00:00
	Motion	00:00:00	00:20:17	00:10:39	00:21:50	00:10:49	00:00:00
NVA Total		00:55:55	01:22:06	01:09:10	01:25:58	01:16:44	01:21:58
Grand Total		01:42:20	01:52:59	01:49:37	01:51:25	01:50:03	01:48:55

Table 14Typical result for a mason crew completing vibrating and finishing concrete for slab in%.

Typical result for a mason crew completing vibrating and finishing concrete for slab section in%								
Activity classification	***Waste classification***	***Mason 1***	***Mason 2***	***Mason 3***	***Mason 4***	***Mason 5***	***Mason 6***	***Crew %***
VA	**-**	45.36%	27.33%	36.90%	22.84%	30.27%	0.00%	26.94%
VA Total		**45.36%**	**27.33%**	**36.90%**	**22.84%**	**30.27%**	**0.00%**	**26.94%**
NVAR	***In process inspection***	0.00%	0.00%	0.00%	0.00%	0.00%	24.74%	4.11%
	Material positioning	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NVAR Total		**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**24.74%**	**4.11%**
NVA (waste)	***Waiting***	43.73%	47.43%	47.91%	57.56%	59.90 %	75.26%	55.37%
	Extra processing	10.91%	7.29%	5.47%	0.00%	0.00%	0.00%	3.88%
	Motion	0.00%	17.95%	9.72%	19.60%	9.83%	0.00%	9.70%
NVA Total		**54.64%**	**72.67%**	**63.10%**	**77.16%**	**69.73%**	**75.26%**	**68.95%**
Grand Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

The concrete vibrating and finishing crew spent only 26.94% of the working hours per slab section on value adding activities (vibrating and finishing concrete), 55.37% on waiting until concrete was placed to some extent, and the rest 9.70% was spent on unnecessary movement (NVA) of masons.

Table 15Typical result for entire concrete crew completing concrete work for slab section in %.

Typical result for entire concrete crew completing concrete work for slab section in %					
Activity classification	***Waste classification***	***Concrete transporting crew***	***Concrete placing crew 1***	***Concrete placing crew2***	***Concrete vibrating and finishing (mason crew)***
VA	**-**	0.00%	27.35%	37.48%	26.94%
VA Total		**0.00%**	**27.35%**	**37.48%**	**26.94%**
NVAR	***In- process inspection***	0.00%	0.00%	0.00%	4.11%
	Material positioning	17.57%	0.00%	0.00%	0.00%
NVAR Total		**17.57%**	**0.00%**	**0.00%**	**4.11%**
NVA (waste)	***Waiting***	27.94%	65.83%	59.14%	55.37%
	Transport	54.49%	0.00%	0.00%	0.00%
	Extra processing	0.00%	0.00%	0.00%	3.88%
	Motion	0.00%	6.82%	3.38%	9.70%
	Defect	0.00%	0.00%	0.00%	0.00%
NVA Total		**82.43%**	**72.65%**	**62.52%**	**68.95%**
Grand Total		100%	100%	100%	100%

4.1.2.2 Case study No.4

The project was a B +G+10 building for one of the case study company's main office building purpose. The total area of the building is 552.15 $m^{2.}$ .The researcher observed concrete work for slab related with 134.52 m^2.Video data collection was used along with data sheet to observe each crew members' activities. The company used ready mix concrete. In addition concrete was placed using power boom (remote pedestal booms), in addition water-reducing, high range admixture was used.

In overall there were 9 workers were involved for placing 99.40 m^3 concrete in 552.15 m^2 area. Among the 9 workers 2 were placing concrete by adjusting the hose attached to the boom ends with the aid of the remote control guy, while 2 workers were placing concrete using shovels, and 5 masons were vibrating and finishing concrete. Basically each crew member were doing the same thing except the masons who were vibrating and finishing concrete. The researcher observed

concrete work associated with 20.92 m^3 concrete in 134.52 m^2 area only. The summary of concrete placing crew along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 16 and Table 17. The summary of concrete vibrating and finishing crew (mason) along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 18 and Table 19 shows masons' crew result on percentile. Finally the summary of the entire crew result on percentile are shown on Table 20.

Table 16Typical result for Concrete placing crew (1) completing placing for slab section.

Typical result for Concrete placing crew (1) completing placing for slab section			
Activity classification	***Waste classification***	***Time at activity***	***% of time at activity***
VA	-	00:55:30	64.12%
VA Total		**00:55:30**	**64.12%**
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	00:31:23	35.88%
NVA Total		**00:31:03**	**35.88%**
Grand Total		**01:26:33**	**100%**

Concrete placing crew No.1 spent 64.12% of the working hours per slab section on value adding activities while the rest 35.88% was spent on waiting while pedestal boom change position and while change between empty and loaded trucks.

Table 17Typical result for Concrete placing crew (2) completing placing for slab section.

Typical result for Concrete placing crew (2) completing placing for slab section			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	-	00:57:07	67.69%
VA Total		**00:57:07**	**67.69%**
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	00:27:16	32.31%
NVA Total		**00:27:16**	**32.31%**
Grand Total		**01:24:23**	**100%**

Concrete placing crew No.2 on the other hand spent 67.69% on value adding activities by placing concrete while the rest 32.31% was spent on waiting until the crew1 finish placing concrete, waiting while pedestal boom change position and while change between empty and loaded trucks.

Table 18Typical result for a mason crew completing vibrating and finishing concrete for slab section.

Typical result for a mason crew completing vibrating and finishing concrete for slab section						
Activity classification	***Waste classification***	***Mason 1***	***Mason 2***	***Mason 3***	***Mason 4***	***Mason 5***
VA	**-**	01:11:05	01:03:30	00:43:55	00:33:53	00:51:19
VA Total		**01:11:05**	**01:03:30**	**00:43:55**	**00:33:53**	**00:51:19**
NVAR	***In-process inspection***	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
	Material positioning	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
NVAR Total		**00:00:00**	**00:00:00**	**00:00:00**	**00:00:00**	**00:00:00**
NVA	***Waiting***	00:22:54	00:28:21	00:42:52	00:50:44	00:41:52
NVA Total		00:22:54	00:28:21	00:42:52	**00:50:44**	00:41:52
Grand Total		**01:33:59**	**01:31:51**	**01:26:47**	**01:24:37**	**01:33:11**

Table 19Typical result for a mason crew completing vibrating and finishing concrete for slab in%.

Typical result for a mason crew completing vibrating and finishing concrete for slab section in%							
Activity classification	**Waste classification**	**Mason 1**	**Mason 2**	**Mason 3**	**Mason 4**	**Mason 5**	**Crew %**
VA	**-**	75.63%	69.13%	50.61%	40.04%	55.07%	58.10%
VA Total		**75.63%**	**69.13%**	**50.61%**	**40.04%**	**55.07%**	**58.10%**
NVAR	**In process inspection**	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Material positioning	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NVAR Total		**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
NVA	**Waiting**	24.37%	30.87%	49.39%	59.96%	59.90%	41.90%
NVA Total		**24.37%**	**30.87%**	**49.39%**	**59.96%**	**44.93%**	**41.90%**
Grand Total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

The mason crew (concrete vibrating and finishing) weighted average result shows that 58.55% was spent on value adding activities by vibrating and finishing concrete while the rest 41.25% was spent on waiting until the concrete placing crew finish placing concrete to a certain extent.

Table 20Typical result for entire concrete crew completing concrete work for slab section in %.

Typical result for entire concrete crew completing concrete work for slab section in %				
Activity classification	**Waste classification**	**Concrete placing crew No. 1**	**Concrete placing crew No.2**	**Concrete vibrating and finishing (mason crew)**
VA	-	64.12%	67.69%	58.10%
VA Total		**64.12%**	**67.69%**	58.10%
NVAR	**In process inspection**	0.00%	0.00%	0.00%
	Material positioning	0.00%	0.00%	0.00%
NVAR Total		**0.00%**	**0.00%**	**0.00%**
NVA(waste)	**Waiting**	35.88%	32.31%	41.90%
NVA Total		**35.88%**	**32.31%**	**41.90%**
Grand Total		**100%**	**100%**	**100%**

4.1.2.3 Comparison of concrete work for slab cases

Concrete work case studies result showed difference both in methodologies used as well as crew allocation for the work. Methodologies used by case study No.4 acquired less time and number of workers than at case study No.3.There were only 9 workers for placing 99.4m^3concrete on case study No.4 and all 9 workers were adding value to the work process on the other hand there were 29 workers placing concrete for placing 82.29m^3 concrete on case study No.3 among which 20 workers were the only once that added value to the work process. The overall waiting time spent by the concrete placing crew on case study No.3 reaches up to 66% while the overall waiting time spent by the concrete placing crew in case study No.4 on maximum reaches up 36%. This as result shows that there was more interruption of flow in the work process due to various reasons like waiting until vibrators are fixed, lack of coordination of workers, waiting until empty mixing trucks are replaced by loaded trucks and waiting until concrete pipes' positions are adjusted on case study No. 3 than there was in case study No. 4. Unnecessary allocation of workers was also a problem on case study No.3 than there was on case study No. 4 which as a result led to doing noting by some of the workers. No time was spent on unnecessary transportation (NVA) of concrete by workers on case study No.4 due to power boom (remote pedestal booms) used for placing concrete. On the other hand on case study No. 3 there were 9 workers spending 54% of the working hours per slab section by pointlessly transporting concrete by carrying heavy weighing

hose attached to concrete pipe ends of the trailer pumps (small general pumps) all the way. Unnecessary movement of workers were also avoided on case study No. 4 due to less number of workers on the other hand on case study No.3, 3%-10% was spent on unnecessary movement of workers like dancing ,walking and wrestling. In addition on case study No.3 17% transporting crew hours per slab section was spent on trying to adjust and fix concrete pipe position (NVAR) while on case study No.4 no time was spent such activities due to the fact the concrete placing hoses are attached to placing boom ends.

4.1.3 Case study No.5 and No.6

Column work

4.1.3.1 Case study No.5

The project was a G+8 building for multipurpose use. The total area of the building is 600m^2. During the time of conducting the case study the building reached 2nd floor. There are totally 30 columns in the building, the researcher observed 8 columns with a size of (600mm × 600mm).The column work has three trades, rebar work, formwork work and concrete work. The company used plywood for formwork preparation and concrete was placed by daily labors after concrete has been dumped to site using trial pumps. There were eight workers each for rebar and carpentry work for the eight columns. On the other hand there were 11 workers involved while placing concrete for one column (1.2m^3 concrete).

I. Rebar work for column

Eight rebar workers were observed while working on eight columns, each working two columns. In addition two rebar workers were working on one column. The major categories and activities of rebar work for Colum are shown on Table 21.

Table 21Categories and activities of rebar work for Column.

Categories of work	Activities
VA	
Value adding	Cutting and tying steel wire
NVAR	
Material positioning	Erecting (positioning) rebar
	Positioning Stirrup
	Adjusting rebar position
In-process Inspection	Checking rebar alignment
	Inspection
	Measuring and marking
NVA	
Waiting	Doing noting while waiting, talking
Transporting	Unnecessary transportation
Extra processing	Rework
Motion	Walking, unnecessary movement
Defect	Defective work

The summary of each crew members' activity along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 22. In addition the summary of the entire crew result on percentile are shown on Table 23 along with chart 3.

Table 22Typical result for rebar crew each completing rebar work for two columns

Typical result for rebar crew each completing rebar work for two columns									
Activity classification	***Waste classification***	***Worker No 1***	***Worker No2***	***Worker No 3***	***Worker No4***	***Worker No 5***	***Worker No 6***	***Worker No 7***	***Worker No 8***
VA	***Value adding***	01:22:00	01:08:54	01:18:21	01:44:33	02:00:05	01:43:40	01:15:10	01:06:10
VA Total		**01:22:00**	**01:08:54**	**01:18:21**	**01:44:33**	**02:00:05**	**01:43:40**	**01:15:10**	**01:06:10**
NVAR	***In-process inspection***	00:00:27	00:07:22	00:11:53	00:01:16	00:03:25	00:05:24	00:12:47	00:02:16
	Material positioning	01:05:45	01:35:11	01:32:10	01:00:45	01:41:11	01:45:31	01:55:51	01:34:33
NVAR Total		**01:06:12**	**01:42:33**	**01:44:03**	**01:02:01**	**01:44:36**	**01:50:55**	**02:08:38**	**01:36:49**
NVA	***Waiting***	00:27:40	0:10:59	00:19:26	00:29:37	00:28:36	00:40:30	00:10:32	00:13:49
	Transport	00:24:31	00:09:34	00:13:32	00:18:42	00:18:06	00:15:49	00:18:56	00:35:05
	Extra processing	00:00:23	00:00:54	00:15:18	00:05:44	00:00:00	00:00:00	00:00:00	00:08:33
	Motion	00:03:51	00:07:02	00:00:00	00:01:57	00:00:00	00:00:00	00:00:00	00:00:00
	Defect	00:00:23	00:00:00	00:14:29	00:14:29	00:05:38	00:05:38	00:00:00	00:00:00
NVA Total		**00:56:48**	**00:28:29**	**01:02:45**	**01:10:29**	**00:52:20**	**01:01:57**	**00:29:28**	**00:57:27**
Grand Total		**03:25:00**	**03:19:56**	**04:05:09**	**03:57:03**	**04:37:01**	**04:36:32**	**03:53:16**	**03:40:26**

Table 23Typical result for rebar crew each completing rebar work for two columns in %

Activity classification	Waste classification	Typical result for rebar crew each completing rebar work for two columns in %								
		Worker No.1	Worker No.2	Worker No. 3	Worker No.4	Work No.5	Worker No.6	Work No.7	Work No.8	Crew%
VA	Value adding	40%	34.46%	31.96%	44.11%	43.35%	37.49%	32.23%	30.02%	36.89%
VA Total		40%	34.46%	31.96%	44.11%	43.35%	37.49%	32.23%	30.02%	36.89%
NVAR	In process inspection	0.22%	3.68%	4.84%	0.53%	1.23%	1.95%	5.48%	1.03%	2.37%
	Material positioning	32.07%	47.61%	37.60%	25.63%	36.53%	38.16%	49.66%	42.89%	38.59%
NVAR Total		32.29%	51.29%	42.44%	26.16%	37.76%	40.11%	55.14%	43.92%	40.96
NVA (waste)	Waiting	13.50%	5.50%	7.93%	12.49%	10.32%	14.65%	4.51%	6.27%	9.56%
	Transport	11.96%	4.78%	5.52%	7.89%	6.53%	5.72%	8.12%	15.92%	8.14%
	Extra processing	0.19%	0.45%	6.25%	2.42%	0.00%	0.00%	0.00%	3.87%	1.63%
	Motion	1.88%	3.52%	0.00%	0.82%	0.00%	0.00%	0.00%	0.00%	0.68%
	Defect	0.18%	0.00%	5.90%	6.11%	2.04%	2.03%	0.00%	0.00%	2.14%
NVA Total		27.71%	14.25%	25.60%	29.73%	18.89%	22.40%	12.63%	26.06%	22.15
Grand total		100%	100%	100%	100%	100%	100%	100%	100%	100%

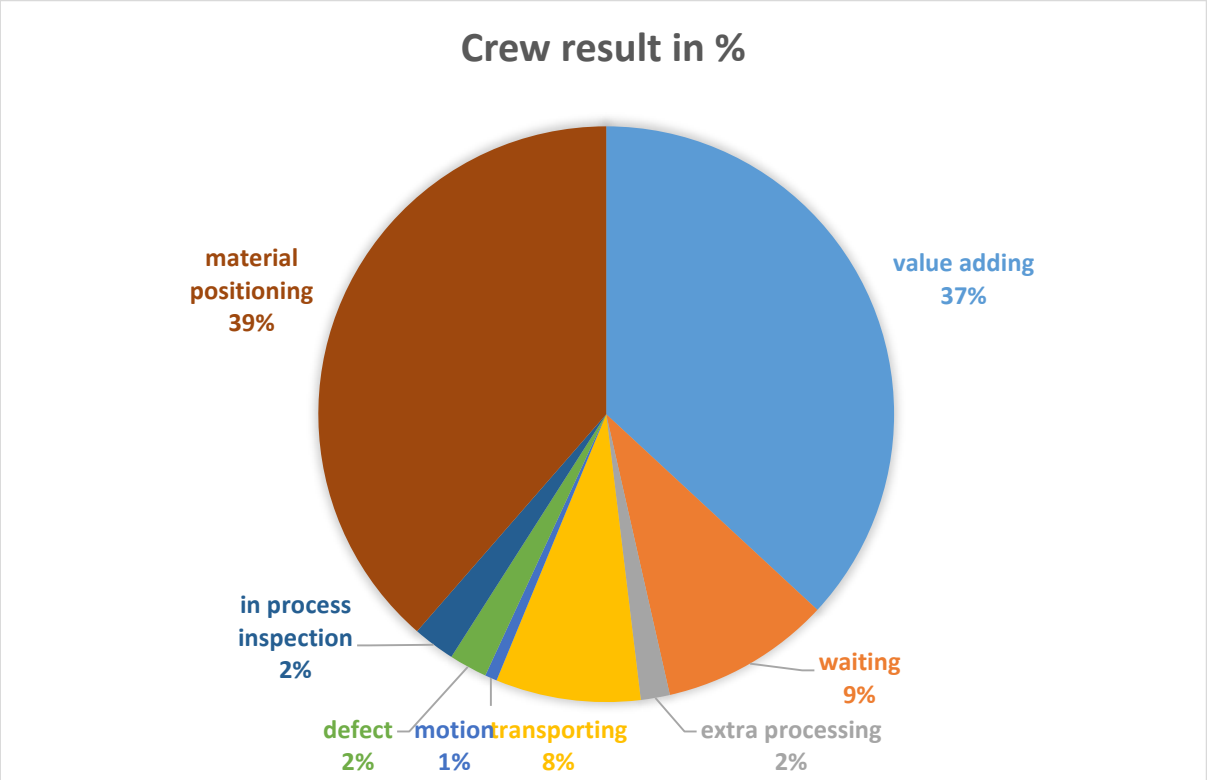


Chart 3Typical result for rebar crew each completing rebar work for two columns.

The weighted average crew result shows that only 36.89% of the working hours per two columns each was spent on value adding activity, 40.96% was spent on NVAR activities and the rest 22.15%was spent on NVA. Among the NVAR activities material positioning (Erecting rebar, positioning stirrup and adjusting rebar position) takes the biggest share which is 38.59% while the rest 2.37% takes in process inspection. Among the NVA activities waiting time takes 9.56% of the working time this refers to the time spent by the workers doing nothing while waiting for the crane to lower rebar, waiting for confirmation order and so on. Unnecessary transportation which includes trying to lift heavy reinforcement bars takes 8.14%. Since rebar columns are done in a stationery position wastes that arise out of unnecessary movement of the workers was almost none. Both Defective work and rework takes 2% in the work process.

II. Formwork for column

Eight carpenters were observed while working on eight columns, each working on two columns. In addition two carpenters were working on one column. The formworks for columns were made of plywood and they were also prepared on site, nevertheless carpenters were only observed while placing already made formworks for column.

According to Walbridge-Aldinger (2000) strict definition for VA activities as "any activity that changes the shape, form, or function of materials or information to meet customer's needs" This definition excludes common construction work such as material handling, inspection or temporary structures. This category can be separated into three subcategories that are required for construction operations, yet have no permanent effect on the finished product. These subcategories include material positioning, in-process inspection, and temporary work and support activities (TWSA), therefore formwork as part of being temporary structure, is categorized as NVAR.

The major categories and activities of formwork for Column are listed on Table 24.

Table 24Categories and activities of formwork for Column.

Categories of work	Activities
VA	
Value adding	-
NVAR	
	Positioning horizontal support
Material positioning	Positioning vertical support
	Positioning diagonal support
	Adjusting formwork position
In-process Inspection	Plumbing and leveling
	Inspection (checking formwork alignment)
	Measuring and marking
TWSA	Erecting formwork
	Nailing formwork
	Nailing horizontal support
	Nailing diagonal support
NVA	
Waiting	Doing noting while waiting, talking
Transporting	Unnecessary transportation
Extra processing	Rework
Motion	Walking, unnecessary movement
Defect	Defective work

The summary of each crew members' activity along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 25 .In addition the summary of the entire crew result on percentile are shown on Table 26 and Chart 4 respectively.

Table 25Typical result for carpenter crew each completing formwork for two columns.

Typical result for carpenter crew each completing formwork for two columns									
Activity classification	***Waste classification***	***Carpenter No.1***	***Carpenter No.2***	***Carpenter No.3***	***Carpenter No.4***	***Carpenter No.5***	***Carpenter No.6***	***Carpenter No.7***	***Carpenter No. 8***
VA	***Value adding***	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
VA Total		00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
NVAR	***In-process inspection***	00:07:08	00:11:26	00:20:07	00:05:25	00:08:40	00:31:03	00:17:10	00:12:59
	Material positioning	00:50:55	00:51:28	00:35:54	00:50:43	00:36:05	00:48:13	00:55:56	00:50:11
	TWSA	01:15:17	01:27:25	00:59:51	01:06:12	01:08:34	01:00:40	01:09:00	01:05:15
NVAR Total		02:13:20	02:30:19	01:55:52	02:02:20	01:53:19	02:19:56	02:22:06	02:08:25
NVA	***Waiting***	01:03:38	00:46:32	01:05:55	01:07:50	00:42:03	00:27:40	01:01:25	01:07:03
	Transport	00:00:00	00:00:00	00:06:36	00:02:16	00:00:00	00:04:52	00:05:00	00:00:00
	Extra processing	00:07:41	00:13:43	00:17:08	00:09:03	00:02:18	00:00:50	00:15:32	00:17:59
	Motion	00:00:00	00:00:00	00:00:00	00:00:00	00:14:41	00:00:00	00:12:47	00:18:13
	Defect	00:01:10	00:00:13	00:02:07	00:04:48	00:01:34	00:00:00	00:07:01	00:11:13
NVA Total		01:12:29	01:00:28	01:31:46	01:23:57	01:00:36	00:33:22	01:41:45	01:54:28
Grand Total		03:25:49	03:30:47	03:27:38	03:25:28	02:53:55	02:53:18	04:03:51	04:02:53

Table 26Typical result for carpenter crew each completing formwork for two columns in %

Activity classification	Waste classification	Typical result for carpenter crew each completing formwork for two columns in %								
		Carpenter No.1	Carpenter No.2	Carpenter No. 3	Carpenter No.4	Carpenter No.5	Carpenter No.6	Carpenter No.7	Carpenter No.8	Group %
VA	Value adding	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
VA Total		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NVAR	In process inspection	3.46%	5.42%	9.82%	2.24%	4.93%	17.92%	7.03%	5.34%	6.85%
	Material positioning	24.74%	24.42%	17.89%	24.68%	20.52%	27.82%	22.94%	20.66%	22.79%
	TWSA	36.58%	41.47%	29.83%	32.22%	41.88%	35.01%	28.30%	26.87%	33.18%
NVAR Total		64.78%	71.31%	57.55%	59.14%	67.33%	80.75%	58.27%	52.87%	62.82%
NVA (waste)	Waiting	30.92%	22.08%	31.75%	32.85%	23.91%	15.96%	25.19%	27.61%	26.56%
	Transport	0.00%	0.00%	3.18%	1.11%	0.00%	2.81%	2.05%	0.00%	1.13%
	Extra processing	7.73%	6.51%	8.25%	4.40%	1.31%	0.48%	6.37%	7.40%	5.06%
	Motion	0.00%	0.00%	0.00%	0.00%	6.56%	0.00%	5.24%	7.50%	2.74%
	Defect	0.57%	0.10%	1.02%	2.34%	0.9%	0.00%	2.88%	4.62%	1.69%
NVA Total		35.22%	28.69%	44.20%	40.86%	32.67%	19.25%	41.73%	47.13%	37.15%
Grand total		100%	100%	100%	100%	100%	100%	100%	100%	100%

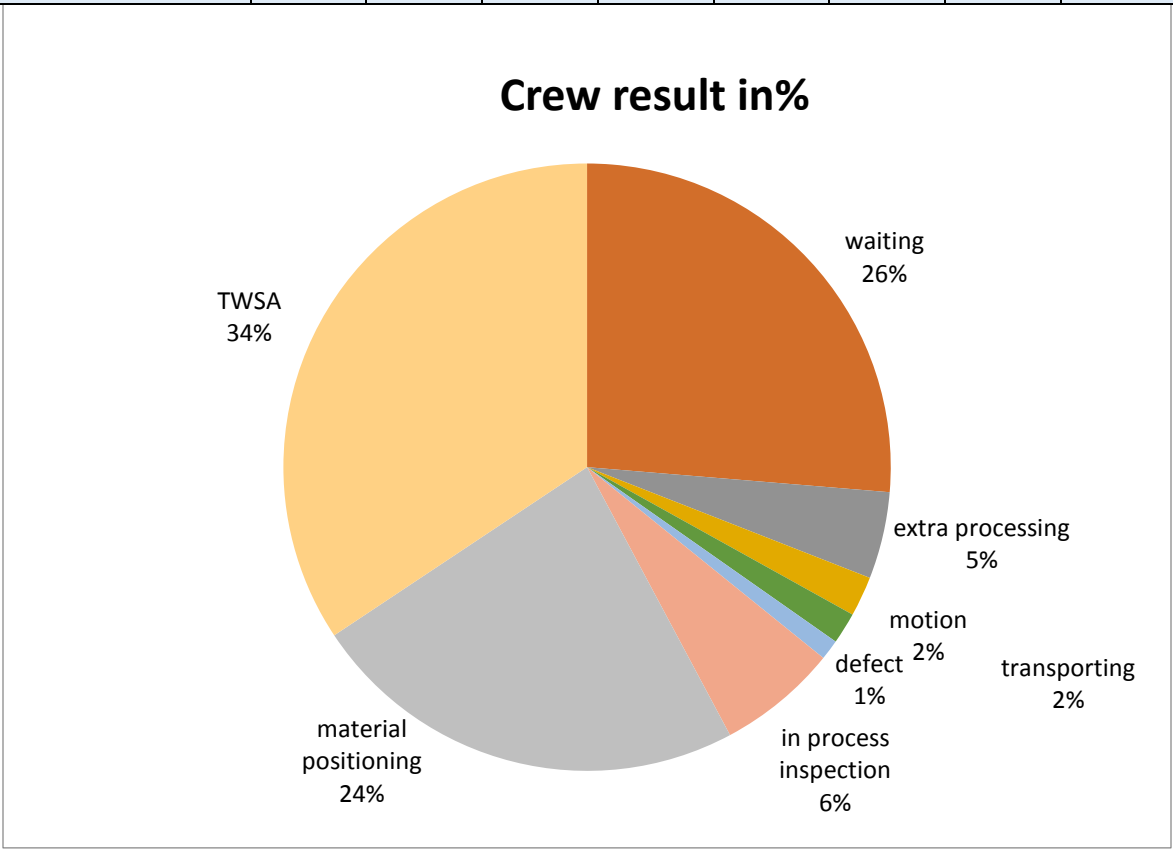


Chart 4 Typical result for carpenter crew each completing formwork for two columns.

According to the carpenters' crew result, 62.82% of the working hours per two columns each was spent on NVAR activities, amongst building temporary and supporting activities (TWSA) takes 32.18%, as well as the prime share among the others, this activities include; erecting formwork, Nailing formwork, Nailing horizontal support and Nailing diagonal support. The other 22.79% of the NVAR was spent on material positioning which includes, Positioning horizontal support, positioning vertical support, positioning diagonal support and adjusting formwork position. The rest 6.85% of the NVAR was spent on Plumbing and leveling, checking rebar alignment and on measuring and marking. On the other hand NVA takes 37.15% while waiting time takes 26.56% among NVA (waste) activities, this as a result shows an interruption of flow in the work process due to various reasons like late delivery of required materials and tools, waiting for the rebar crew until rebar works are completed and waiting for confirmation order and so on. The fact that the plywood formwork were re-used several times the carpenters were forced to fix defective formworks, this led to rework while trying to erect and adjust the irregular surface of the forms, this takes 5.06% of the crew working hours per two columns each.

III. Concrete work for column

After Concrete has been dumped at a convenient position using trailer pumps, daily laborers transported concrete all the way to the columns using buckets. For each column concrete work, two workers were consecutively standing and continuously passing the buckets full of concrete to the last person who is standing on formwork stands and actually placing concrete to the columns, while six laborers were transporting concrete using buckets and continuously passing the buckets to those two workers at stationery position and passing the buckets to the worker actually placing concrete to the columns, one mason standing on formwork edge was vibrating and finishing concrete. In addition two laborers were continuously filling buckets with concrete to the transporting crew. The major categories and activities of concrete work are presented on Table 27 below.

Table 27Categories and activities of column concrete work.

Categories of work	Activities
VA	
Value adding	Placing concrete
	Vibrating concrete
	Finishing concrete
NVAR	
Material positioning	Positioning(fixing) pump position
NVA	
Waiting	Doing noting while waiting for concrete
Transporting	Unnecessary transportation of concrete by the workers

The number workers involved for one column concrete work were plenty (10workers) in addition the activities of workers was redundant, as a result the concrete work associated with only one column is considered. Summary of concrete placing crew is shown on Table 28. The summary of concrete transporting crew is shown on Table 29 and one masons' activity associated with only one column is shown on Table 30. Throughout the whole concrete work process, the concrete placing crew and the mason was the once who actually contributed to value adding activities while the concrete transporting crew were just transporting concrete while it could easily have been done by the available tower crane.

Table 28Typical result for Concrete placing crew completing placing concrete for one column.

Typical result for Concrete placing crew completing placing concrete for one column			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	*Value adding*	00:20:26	68.17%
VA Total		**00:20:26**	**68.17%**
NVA	*Waiting*	00:09:23	31.83%
NVA Total		**00:09:23**	31.83%
Grand Total		**00:29:29**	**100%**

The concrete placing crew spent 68.17% of the concrete placing hours per column on value adding activates while the rest was spent on waiting until concrete is transported by the laborers.

*Table 29*Typical result for Concrete transporting crew completing transporting for one column.

Typical result for Concrete transporting crew completing transporting for one column			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	*Value adding*	00:00:00	0.00%
VA Total		**00:00:00**	**0.00%**
NVA	*Waiting*	00:11:50	40.95%
	Transport	00:17:04	59.05%
NVA Total		**00:28:54**	**100%**
Grand Total		**00:28:54**	**100%**

The concrete transporting crew spent no time on value adding activity.40.95% of the crew working hours was spent on waiting until the buckets are filled with concrete and the rest 59.0% was spent on transporting concrete using buckets of.

Table 30Typical result for mason completing vibrating and finishing concrete for one column.

Typical result for mason completing vibrating and finishing concrete for one column			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	*Value adding*	00:10:14	30.04%
VA Total		**00:10:14**	**30.04%**
NVA	*Waiting*	00:03:50	69.96%
NVA Total		**00:03:50**	**69.96%**
Grand Total		**00:34:04**	**100%**

On the other hand one Mason spent 30.04% of the working hour per column on value adding activities (vibrating and finishing concrete) while all 69.96% was spent on waiting for placing and transporting crew while transporting and placing and until reached appropriate height for vibrating and finishing concrete, this also shows unnecessary allocation of workers for specific work in a given time.

4.1.3.2 Case study No.6

The project was a 2B+G+8 building for Apartment purpose. The total area of the building is 1070m^2. There are two sections in the building, the case study focuses in one of the sections. The first section has totally area of 507m^2. The building reached 4th floor when the research was

conducted and there were 38 columns on the floor, the researcher observed 8 columns with a size of (600mm×600mm).The column work has three trades, rebar work, formwork work and concrete work. The company uses modern modular formworks for shear walls and columns that are delivered from Italy. Concrete was placed using power boom (remote pedestal booms).There were eight workers involved, each for rebar and carpentry work for the eight columns and 3 workers were involved while placing one column (1.00 m^3 concrete).

I. Rebar work for column

Eight rebar workers were observed while working on eight columns, each working two columns. In addition two rebar workers were working for one column. The major categories and activities of rebar work for Colum are shown on Table 31

Table 31Categories and activities of rebar work for column.

Categories of work	Activities
VA	
Value adding	Cutting and tying steel wire
NVAR	
Material positioning	Erecting (positioning)rebar
	Positioning Stirrup
	Adjusting rebar position
In-process Inspection	Checking rebar alignment
	Inspection
	Measuring and marking
NVA	
Waiting	Doing noting while waiting, talking
Transporting	Unnecessary transportation
Extra processing	Rework
Motion	Walking, unnecessary movement
Defect	Defective work

The summary of each crew member's activity along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 32 .In addition the summary of the entire crew result on percentile are shown at Table 33 and Chart 5 respectively.

*Table 32*Typical result for rebar crew each completing rebar work for two columns.

Typical result for rebar crew each completing rebar work for two columns									
Activity classification	***Waste classification***	***Worker No 1***	***Worker No2***	***Worker No 3***	***Worker No4***	***Worker No 5***	***Worker No 6***	***Worker No 7***	***Worker No 8***
VA	***Value adding***	01:35:24	01:42:14	01:26:43	01:14:29	01:44:10	01:28:03	01:36:58	01:27:38
VA Total		**01:35:24**	**01:42:14**	**01:26:43**	**01:14:29**	**01:44:10**	**01:28:03**	**01:36:58**	**01:27:38**
NVAR	***In-process inspection***	00:11:40	00:12:07	00:07:03	00:11:22	00:13:24	00:13:32	00:08:01	00:15:08
	Material positioning	01:52:33	01:26:25	01:23:46	01:23:45	01:25:37	01:44:16	01:12:16	01:15:23
NVAR Total		**02:04:13**	**01:38:32**	**01:30:49**	**01:35:07**	**01:39:01**	**01:57:48**	**01:20:17**	**01:30:31**
NVA	***Waiting***	00:24:53	00:12:37	00:09:54	00:15:03	00:19:02	00:11:33	00:10:03	00:20:03
	Transport	00:10:08	00:40:16	00:18:24	00:29:10	00:22:00	00:13:51	00:15:29	00:27:39
	Extra processing	00:00:00	00:00:00	00:09:58	00:00:00	00:00:00	00:13:36	00:09:56	00:00:00
	Motion	00:00:00	00:01:48	00:06:38	00:09:36	00:00:00	00:02:04	00:08:15	00:00:00
	Defect	00:00:00	00:00:00	00:03:16	00:03:42	00:03:33	00:03:30	00:05:39	00:00:00
NVA Total		**00:35:01**	**00:54:41**	**00:48:10**	**00:57:31**	**00:44:35**	**00:44:34**	**00:49:22**	**00:47:42**
Grand Total		**04:14:38**	**04:15:27**	**03:45:42**	**03:47:07**	**04:07:46**	**04:10:25**	**03:46:37**	**03:45:51**

*Table 33*Typical result for rebar crew each completing rebar work for two columns in %.

Activity classification	***Waste classification***	***Typical result for rebar crew each completing rebar work for two columns in %***								
		Worker No.1	***Worker No.2***	***Worker No. 3***	***Worker No.4***	***Work No.5***	***Worker No.6***	***Work No.7***	***Work No.8***	***Crew%***
VA	***Value adding***	37.47%	40.02%	38.42%	32.80%	42.04%	35.16%	42.79%	38.81%	38.44%
VA Total		**37.47%**	**40.02%**	**38.42%**	**32.80%**	**42.04%**	**35.16%**	**42.79%**	**38.81%**	**38.44%**
NVAR	***In -process inspection***	4.58%	4.74%	3.13%	5.00%	5.41%	5.40%	3.54%	6.70%	4.83%
	Material positioning	44.20%	33.83%	37.11%	36.88%	34.56%	41.64%	31.89%	33.38%	36.79%
NVAR Total		**48.78%**	**38.57%**	**40.24%**	**41.88%**	**39.97%**	**47.04%**	**35.43%**	**40.08%**	**41.62**
NVA (waste)	***Waiting***	9.77%	4.94%	4.39%	6.63%	7.68%	4.61%	4.43%	8.88%	6.43%
	Transport	3.98%	15.76%	8.15%	12.84%	8.88%	5.53%	6.83%	12.24%	9.25%
	Extra processing	0.00%	0.00%	4.41%	0.00%	0.00%	4.43%	4.38%	0.00%	1.75%
	Motion	0.00%	0.71%	2.94%	4.22%	0.00%	0.83%	3.64%	0.00%	1.48%
	Defect	0.00%	0.00%	1.45%	1.63%	1.43%	1.40%	2.49%	0.00%	1.03%
NVA Total		**13.75%**	**21.41%**	**21.34%**	**25.32%**	**17.99%**	**17.80%**	**21.78%**	**21.12%**	**19.94%**
Grand total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

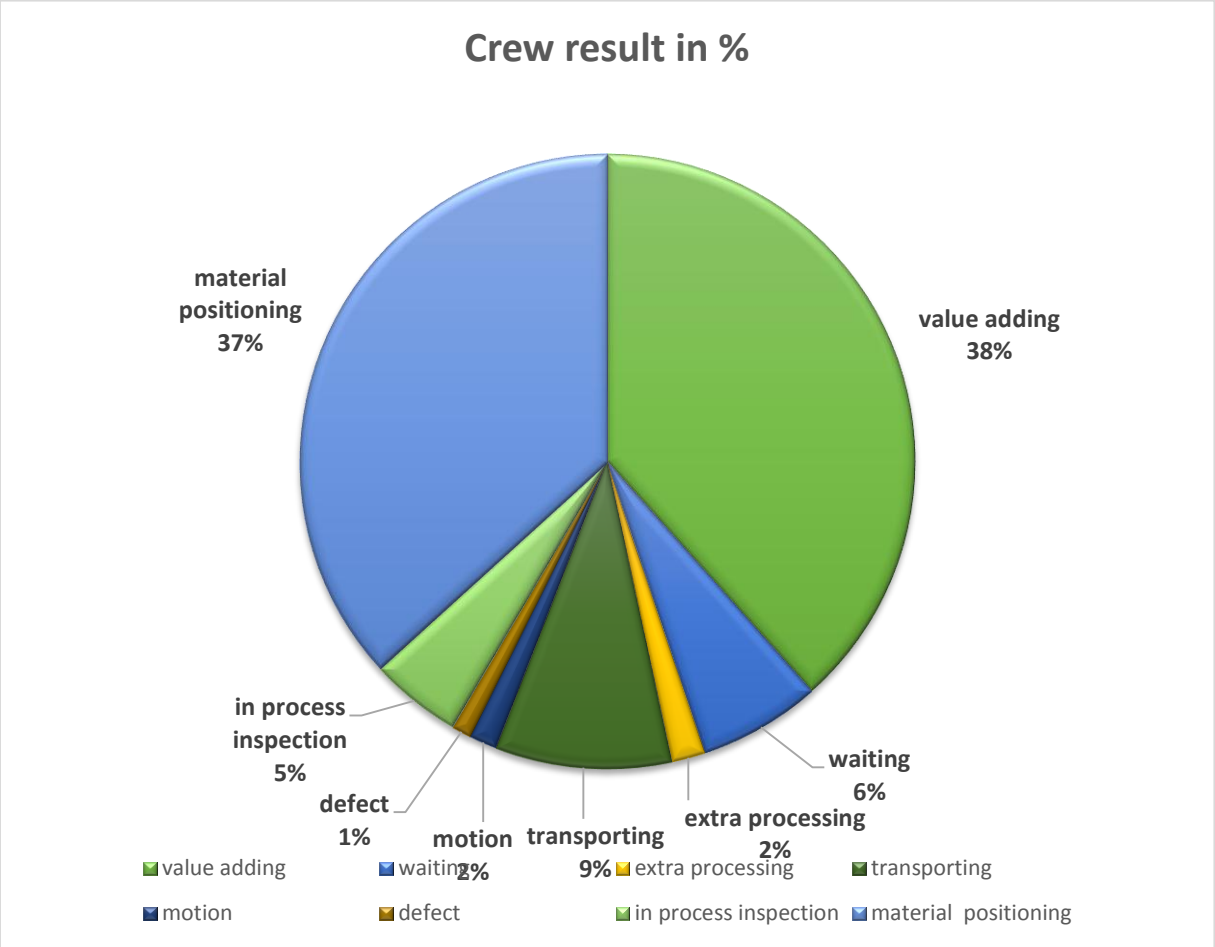


Chart 5 *Typical result for rebar crew each completing rebar work for two columns.*

The weighted average crew result shows that 38.44% of the crew working hours per two columns each was spent on VA, 41.62% was spent on NVAR activities while the rest 19.94% was spent on NVA (waste). VA adding activities include cutting and tying steel wire. Among the 41.62% of NVAR activities material positioning takes the biggest sharer by taking 36.79%, which includes erecting reinforcement bar, positioning stirrup and adjusting rebar position . The rest 5% of NVAR was spent on in-process inspection activities like checking rebar alignment and measuring and marking. Among the 20% of NVA activities waiting time takes 6.43% which includes waiting until reinforcement bars are transported by the crane and waiting for confirmation order. Additional 9.25% of the NVA was spent by unnecessary transportation of heavy weighing reinforcement bars by the workers while the tower crane was operating. Another 1.48% of NVA

was spent on unnecessary movement of workers. Defective work and rework takes 1.03% and 1.75% respectively.

II. Formwork for column

Eight carpenters were observed while working on eight columns, each working two columns. In addition two carpenters were working on one column. The formworks used for columns are modular type and are assembled on site. Major categories and activities of formwork for column are listed on Table 34 as below;

Table 34Categories and activities of formwork for Column.

Categories of work	**Activities**
VA	
Value adding	-
NVAR	
	Positioning wedge
Material positioning	Positioning zinc coated distancing steel bar
	Positioning pin
	Positioning props
	Adjusting formwork position
In-process Inspection	Checking formwork alignment
TWSA	Erecting formwork
	Locking formwork with pin and wedge
	Locking formwork with head arrester
	Tying support with wire
NVA	
Waiting	Doing noting while waiting, talking
Transporting	Unnecessary transportation
Extra processing	Rework
Motion	Walking, unnecessary movement
Defect	Defective work

The summary of each crew's activity along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 35.In addition the summary of the entire crew result on percentile are shown on Table 36and chart 6.

*Table 35*Typical result for carpenter crew each completing formwork for two columns.

Typical result for carpenter crew each completing formwork for two columns									
Activity classification	***Waste classification***	***Carpenter No.1***	***Carpenter No.2***	***Carpenter No.3***	***Carpenter No.4***	***Carpenter No.5***	***Carpenter No.6***	***Carpenter No.7***	***Carpenter No. 8***
VA	***Value adding***	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
VA Total		**00:00:00**	**00:00:00**	**0:00:00**	**00:00:00**	**00:00:00**	**00:00:00**	**00:00:00**	**00:00:00**
NVAR	***In-process inspection***	00:10:40	00:06:21	00:03:58	00:03:25	00:12:38	00:11:36	00:13:22	00:16:29
	Material positioning	00:48:56	00:38:44	01:01:50	01:04:41	00:44:18	00:42:30	00:49:12	00:33:23
	TWSA	00:39:01	00:37:15	00:42:07	00:37:58	00:55:11	00:50:43	00:47:48	00:39:37
NVAR Total		**01:38:37**	**01:22:20**	**01:47:55**	**01:46:04**	**01:52:07**	**01:44:49**	**01:50:22**	**01:29:29**
NVA	***Waiting***	00:14:48	00:18:53	00:11:32	00:15:24	00:13:28	00:17:13	00:17:29	00:21:47
	Transport	00:00:00	0:14:32	00:03:45	00:07:14	00:00:00	00:01:29	00:11:50	00:03:45
	Extra processing	00:00:00	00:00:00	00:18:19	00:02:22	00:00:00	00:00:00	00:02:22	00:00:25
	Motion	00:02:15	00:00:43	00:00:00	00:02:33	00:06:43	00:08:03	00:02:47	00:02:33
	Defect	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
NVA Total		**00:17:03**	**00:34:08**	**00:18:19**	**00:27:33**	**00:20:11**	**00:26:45**	**00:34:18**	**00:28:30**
Grand Total		**01:55:40**	**01:56:28**	**02:06:14**	**02:13:37**	**02:12:18**	**02:11:34**	**02:24:40**	**01:57:59**

Table 36Typical result for carpenter crew each completing formwork for two columns in %.

Activity classification	***Waste classification***	***Typical result for carpenter crew each completing formwork for two columns in %***								
		Carpenter No.1	***Carpenter No.2***	***Carpenter No. 3***	***Carpenter No.4***	***Carpenter No.5***	***Carpenter No.6***	***Carpenter No.7***	***Carpenter No.8***	***Crew%***
VA	***Value adding***	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
VA Total		**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
NVAR	***In process inspection***	9.23%	5.45%	3.15%	2.56%	9.55%	8.82%	9.24%	13.97%	7.71%
	Material positioning	42.30%	33.26%	48.98%	48.41%	33.48%	32.30%	34.01%	28.29%	37.66%
	TWSA	33.73%	31.98%	33.36%	28.41%	41.71%	38.55%	33.04%	33.58%	34.33%
NVAR Total		**85.26%**	**70.69%**	**85.49%**	**79.38%**	**84.74%**	**79.67%**	**76.29%**	**75.84%**	**79.70%**
NVA (waste)	***Waiting***	12.80%	16.21%	9.14%	11.53%	10.18%	13.08%	11.97%	18.46%	12.80%
	Transport	0.00%	12.48%	2.97%	5.41%	0.00%	1.13%	8.18%	3.18%	4.18%
	Extra processing	0.00%	0.00%	2.40%	1.77 %	0.00%	0.00%	1.64%	0.36%	0.80%
	Motion	1.94%	0.62%	0.00%	1.91%	5.08%	6.12%	1.92%	2.16%	2.52%
	Defect	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
NVA Total		**14.74%**	**29.31%**	**14.51%**	**20.62%**	**15.26%**	**20.33%**	**23.71%**	**24.16%**	**20.30%**
Grand total		**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

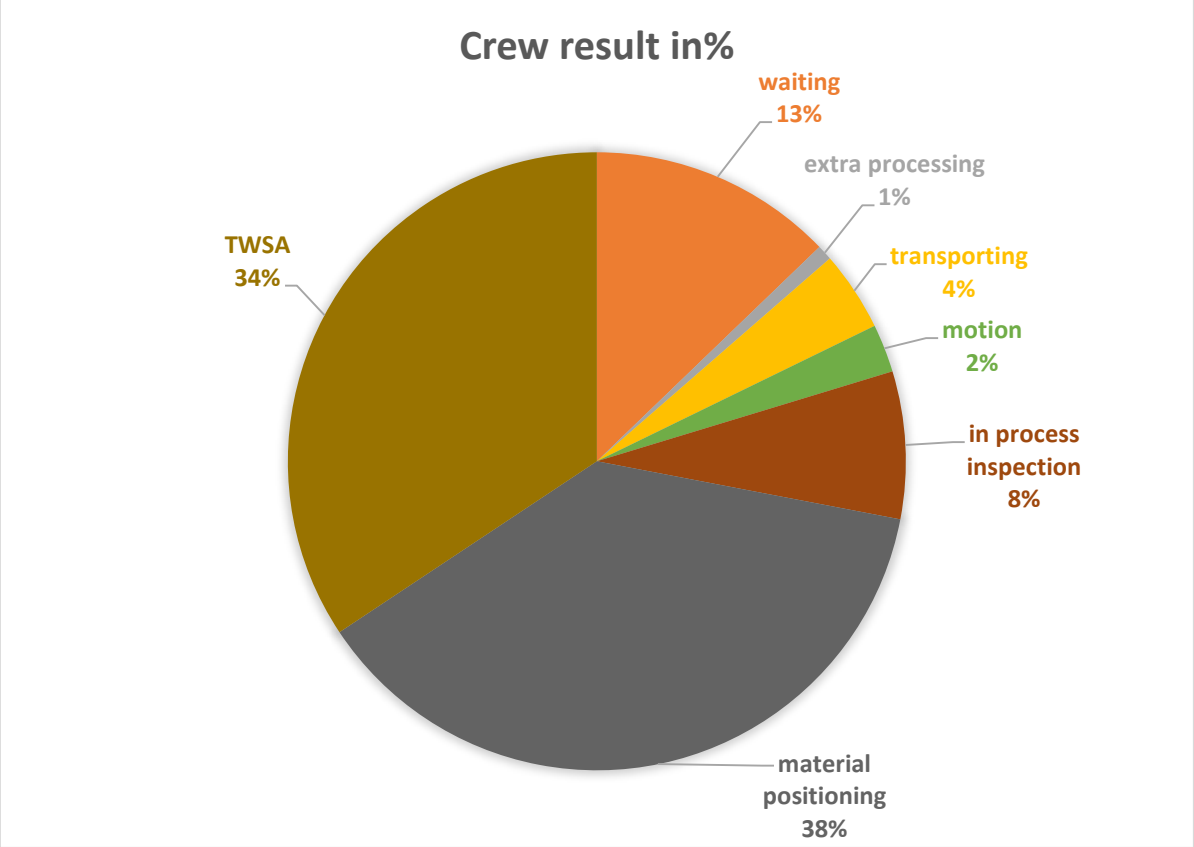


Chart 6 Typical result for carpenter crew each completing formwork for two columns.

As the weighted average crew result shows 79.70%of the carpenters working hour per two columns each was spent on NVAR activities while the rest 20% are spent on NVA activities. Among NVAR activities material poisoning takes 37.66% also the biggest share, this activities comprise of positioning pin and wedge, positioning zinc coated distancing steel bar, positioning props and adjusting formwork position. The other 34.33% of the NVAR are spent on TWSA, this includes; erecting formwork, locking formwork with pin and wedge, locking formwork with head arrester and tying timber support with wire. The rest 8% of NVAR activities was spent on in-process inspection including checking formwork alignment. Among NVA (west) activities 12.8% are spent on waiting time i.e. waiting for carpenter helpers until they finish transporting heavy weighing formworks and waiting for confirmation order. While the rest 4.18% and 2.52% respectively were spent on unnecessary transportation and movement of workers. Since formworks are segmental defect and rework are almost none.

III. Concrete for columns

Power boom (remote pedestal booms) were used for placing column concrete. Three workers were involved two were placing concrete by adjusting attached hose to the boom while one was vibrating concrete. The major categories and activities of concrete work are shown on Table 37 as below;

Table 37Categories and activities of concrete work.

Categories of work	Activities
VA	
Value adding	Placing concrete
	Vibrating concrete
	Finishing concrete
NVA	
Waiting	Waiting time(doing noting while waiting for concrete truck, talking)

The summary of each mason crew's activity along with waste classification and actual time spent on VA, NVAR and NVA activities are presented on Table 38, Table 39 and Table 40 respectively.

Table 38Typical result for mason No.1 completing placing concrete for one column.

Typical result for mason No.1 completing placing for one column			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	*Value adding*	00:07:26	80.80%
VA Total		**00:07:26**	80.80%
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	00:01:46	19.20%
NVA Total		**00:01:46**	**19.20%**
Grand Total		**00:09:12**	**100%**

Masons No.1 spent 80.8% on value adding activities through placing concrete by adjusting attached hoses to powered boom and the rest 19.20% was spent on waiting for the remote control guy to adjust the boom position.

Table 39Typical result for mason No.2 completing placing concrete for one column.

Typical result for mason No.2 completing placing for one column			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	*Value adding*	00:07:26	80.80%
VA Total		**00:07:26**	80.80%
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	00:01:46	19.20%
NVA Total		**00:01:46**	**19.20%**
Grand Total		**00:09:12**	**100%**

Masons No.2 spent 80.8% on value adding activities through placing concrete by adjusting attached hoses to powered boom and the rest 19.20% was spent on waiting for the remote control guy to adjust the boom position.

Table 40Typical result for mason No. 3 completing placing concrete for one column.

Typical result for mason No. 3 completing placing concrete for one column			
Activity classification	***Waste classification***	**Time at activity**	**% of time at activity**
VA	*Value adding*	00:09:05	81.10%
VA Total		**00:09:05**	**81.10%**
NVAR		00:00:00	0.00%
NVAR Total		**00:00:00**	**0.00%**
NVA	*Waiting*	00:02:07	18.90%
NVA Total		**00:02:07**	**18.90%**
Grand Total		**00:11:12**	**100%**

Mason No.3 spent 81% on value adding activity by vibrating and finishing concrete and the rest 19% was spent on waiting until concrete placing process reached to some extent height.

4.1.3.3 Comparison of column work cases

Normally case study No.5 and case study No.6 focuses on column work. Column work has three trades including rebar work, formwork and concrete work .Different mechanisms, materials and machineries were used by the two companies. Comparison between the two case studies are discussed divided in to three sections as follows;

I. Rebar work for column

Basically there was no much difference between case study No. 5 and case study No. 6 on rebar work for column in terms of duration of the work and methods used by the companies.in both case studies, almost 20% of the working time was spent on NVA (waste) activities among which in both cases waiting time and unnecessary transportation of heavy weighing reinforcement bars by workers takes considerable amount of time. Waste that arise out of unnecessary movement was almost insignificant in both case studies due to the nature of the work (stationary position). The probability of making defective work was also low in both cases but defective works were more observed in case study No. 5 than there was in case study No. 6.Material positioning (NVAR) in both case studies took more than 35%, these activities include, positioning erecting rebar, positioning stirrup and adjusting rebar position.

II. Formwork for columns

According to this research concept (lean construction concept) anything that is temporarily built element is NVAR activity, as a result in both case studies formwork is part of NVAR activities. But the different mechanisms and materials used by the companies showed an insight on how working hours spent on temporarily built and supporting activities (NVAR) can be shortened.

As it was mentioned earlier on case study No.5 plywood were used to prepare formworks for columns in addition these formworks are prepared on site. On the other hand on case study No. 6 the company uses modern modular formworks delivered from Italy. In addition working hours spent by the carpenter crew was less on case study No.6 than case study No.5. Waiting time of carpenter crew at case study No. 6 was on average 12% less due to readily available modular formworks. In addition on case study No 6 the probability of making defective works and reworks were almost none while in case of case study No. 5 due to continuous reuse of plywood formworks than required, rework was common and it also reaches up to 5%.

III. Concrete work for column

Concrete work at case study No.5 and No.6 used different methods. At case study No. 5 after concrete has been transported at a convenient position, daily labors transport concrete to the columns using buckets while on case study No. 6 concrete was placed directly to were the columns

are using power boom (remote pedestal booms). On case study No. 5 there were 11 workers involved for one column concrete placement on the other hand there were only 3 workers for one column concrete placement. Method used by case study No.6 took half the time of case study No.5 for placing concrete. In addition all the three workers on case study No.6 contributed to value adding activities (placing, vibrating and finishing concrete) while on case study No.5 only 4 workers among 11 were contributing to value adding activities while the rest were transporting concrete using buckets.

4.2 View of construction wastes by the selected companies

Questionnaires were distributed among construction companies where the case studies were conducted, in order to perceive full understanding on how the company's representatives (site level) understand construction waste. The response to the question are summarized as follows.

Company A (case study No. 1)

Construction waste exists almost in all projects, it occurs due to excess usage of construction materials like cement, aggregate, sand the like.

Company B (case study No. 2)

Construction wastes are wastes related to material, manpower, equipment and time according to our country construction trend the main waste of the construction time and resource.

Company C (case study No. 3)

Construction waste can be seen as any inefficient and annuitized time, material and manpower in any construction company.

Company D site 1 (case study No.4)

Any things and conditions that could affect directly or indirectly the quality, time and allotted budget of the construction project.

Company E (case study No. 5)

Construction wastes are defined as one of the three

1. Miss management of manpower or not assigning the right manpower for the right task.
2. Material waste, improper material stock or excess usage of materials for defined activity
3. Equipment miss management, not using the right task or excess use of equipment.

Company D site 2 (case study No. 6)

Construction of waste mainly happen on physical or construction materials in case of production application and due to modification of wrongly done or manufactured products on site and production area.

4.2.1 Discussion on views of construction wastes by the selected companies

Generally almost all of the respondents (project managers) understand construction wastes as any unnecessary utilization of construction material, equipment and manpower. In addition project managers at company B, C and D (site 1) mentioned any activity that directly or indirectly affects construction time also as a waste. Project managers at company A and company E mentioned that any over production and unnecessary stock of construction materials like cement, aggregate and sand is also a waste. In addition Construction manager at company D (site 1) also understand construction as anything or activity that affects the quality of project and construction manager at company D (site) understand construction waste anything that is wrongly done as a waste. Nevertheless Formoso et al. (2002) recommended broader definition of waste to include not only material waste but also waste generated in a construction project such as waiting times, transportation times, and etc. In addition Womack & Jones (2003) mentioned Waste exists in different forms, including over-production, waiting, unnecessary movement, carrying unnecessary inventory, and rework. Furthermore Koskela (1992) also states that a systematic attempt for identifying wastes in construction processes (flow wastes in lean thinking terms) has not been done by the construction management practitioners until lean construction concept was introduced. Innovative waste categorization, which is considered lean thinking concept.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Generally the main objective of this research was to study construction site wastes based on lean construction concept on selected construction sites. In doing so three major activities were selected (rebar work, concrete work and column work) then two case studies were conducted for each selected activities to identify and categorize each workers activity in a crew member based on lean concept of waste. In overall six case studies at six construction sites were conducted. After analyzing all the collected data conclusions were made in this chapter as follows;

1. In all case studies conducted, working times spent on NVA activities prevailed taking considerable amount of time. In addition among the NVA activities waiting time overcame taking the biggest share in almost all case studies, this indicates an interruption of flow in work process due to various reasons. Furthermore excessive allocation of workers on some of the case studies led to unproductive working hours (doing nothing).

2. By separating rebar bending and cutting places from actual working site, wastes that arise out of unnecessary inventory can be avoided in addition associated waiting time, unnecessary movement and unnecessary transportation of workers can possibly be reduce.

3. Well organized and planned crew allocation in the work can lead to less waiting time and interruption of flow in the work process.

4. As proven by the case studies using better technologies (machineries and materials) reduced NVAR activities and NVA activities like waiting time, unnecessary transportation, defective work and reworks.

5. On the formwork for column cases, no time was spent on value adding activities due to the fact that formwork work process is categorized as NVAR (temporary work and supporting)

activity. In addition waiting time, defective work and reworks can be minimized by using readily available modular formworks.

6. Finally project managers at case studies were questioned to describe construction waste in their own terms and the results showed that they all understand construction wastes in physical terms i.e. any loss of materials, equipment and manpower.in addition some of the project managers understand construction waste as any unutilized working hours and some as anything that is done wrong as waste.

5.2 Recommendations

All this point towards a point where construction wastes should not only be seen as physical wastes. This paper as a result showed other ways of understanding construction wastes (non-physical wastes) which could help insight contractors and all parties involved a better understanding of flow in the work process. Based on the conclusion made the recommendations are drawn as follows;

1. The research strongly believes that Construction Companies should take the first steps in understanding non- physical wastes that are (Overproduction, Time on hand (waiting), Transportation, Additional/Inappropriate Processing, Inventories, Movement and Making Defective Products) that exists on construction sites, in order to maximize value to customers and minimize cost.
2. In order to avoid waiting time the whole work flow process from inception to completion should be thought of carefully in addition any interruption of flow in the work process should be avoided as much as possible by mapping the value stream of the project carefully with all concerned parties including clients, contractors, consultants, subcontractors and suppliers.
3. Working crew allocation should be well-planned otherwise wastes that arises of unnecessary movement (motion) and waiting time increase.
4. Site layouts and working spaces should be well planned to avoid wastes that arise out of unnecessary transportation and movements of the workers.

5. Unnecessary transportation (NVA) of heavy weighing materials like reinforcement bar and concrete by workers should as much as possible be avoided by using the available machineries and equipment efficiently.
6. As proven by the case studies better technologies (machineries and materials) should be used to reduce NVAR activities, waiting time, unnecessary transportation, defective work and reworks.
7. Wastes that arise out of unnecessary stock of construction materials (inventory) can possibly be avoided by having separate workshops, using ready mix concrete and modular elements.
8. Time spent on NVAR activities like temporary work and supporting activities (formwork) can possibly be minimized by using better technologies(materials and equipment), in addition associated NVA activities like waiting time, defective work and re-works can be avoided.

5.3 Recommendations for further study

Lean construction has several tools and techniques, which are uncovered in this paper. Some of the tools and techniques include last planner: a production planning and controlling system, lean project delivery system: a conceptual framework developed to guide the implementation of lean construction and TFV theory. Conducted researches confirmed that the implementation of such lean tools and techniques had significantly reduced waste and improved performance in construction projects, as a result further studies are required on these matters.

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Appendices