Thesis for the Degree of Doctor of Philosophy

Waste Problems in Vietnam Construction Industry Based on Lean Philosophy

by

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Interdisciplinary Program of Construction Engineering and Management

The Graduate School

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A dissertation

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Abstract

Waste has been considered as a great source of value losses of construction projects under the viewpoint of stakeholders. Nowadays, waste is defined as not only related to materials, but also related to time for non-contributory and contributory activities such as waiting, inspection, idle, transport, etc. Thus, there are many causes derived from the reality for waste occurrence. Among them, poor production planning and control has been defined as the most frequent cause. This research aims to examine the waste problems in Vietnam construction industry based on the philosophies of lean production. Previous studies have shown that Lean Construction (LC) proposes an approach to design production processes to reduce wastes in order to create the maximum amount of value.

There are six objectives that have been formulated to conduct this study including: (1) examine general perception of the local construction professionals with the new waste concepts in LC; (2) identify main waste factors and their cause in current construction performance; (3) investigate the latent relationships between waste factors; (4) determine the "Waste Occurrence Level Indicators" (WOLI) for the construction industry, (5) develop a model to predict the impact of wastes on project performance cost; and (6) analyze the main waste factors that have strong impact on project cost.

In addition, a comparison with some selected countries was then made to gain the comprehensive view about waste problems.

As mentioned early, the foundation of this study was based on principles and philosophies of lean production. The population of the survey are the professionals who have experience in construction project management in Ho Chi Minh City, Vietnam. Due to the certain limitations, the non-probability sampling has been applied in this study. The method used for collecting data was questionnaire survey according to the opinions from several experts. All uncompleted feedbacks from respondents were deleted to increase the reliability of data. The tools used for data analysis included both descriptive and inferential statistical analysis.

The main results of analysis have shown that the professionals in construction industry highly perceived the new concepts of waste. However, these wastes were not controlled well by them in the practice. Moreover, there was no interrelationship between recognition, control, and frequency of wastes. According to the ranking of frequency, the main waste factors were identified, as well as the main causes. Through the cause-and-effect analysis, people-related cause group was found as the most influent group for all wastes. Based on factor analysis, there were five components extracted from nineteen initial waste factors with 56.7% of explained variance. Based on these five components, the "Waste Occurrence Level Indicator" (WOLI) was defined as 61.55 in the scale of 100. It indicates that level of waste in the construction industry is quite high. Furthermore, based on the respondents' experience, the average project cost loss due to wastes was identified as up to 9.36% of total cost. Two models have been developed to predict the effect of wastes on project performance cost, i.e., Artificial Neural Network (ANN) model and Linear Regression (LR) model. The results showed that ANN

model (MAPE = 1.35%, and R^2 = 91.1%) produces the higher degree of accuracy compared to the LR model (R^2 = 79.8%). The main waste factors that have strong impact on the project performance cost were then determined by elasticity test. The main contribution of this study is the examination on the status of wastes that are related to time used to complete a project because the traditional viewpoint only focused on wastes related to resource.

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CHAPTER 1

INTRODUCTION

1.1 Research background

Construction is an important sector of the economy for all countries around the world. It normally accounts for a large proportion in total employment of a country; thus, it makes a significant contribution to the whole revenue of that country. However, construction industry is still facing a number of contingent problems that need to be solved to improve its efficiency. These problems were known as low productivity, poor safety, inferior working conditions, and insufficient quality (Koskela, 1993). The phenomenon of poor performance and conditions in construction has long been recorded by many researchers and practitioners throughout the world both in developed countries and developing countries.

Nowadays, in the period of increasing competition, the scarcity of skilled labor and the need to improve construction quality are the key challenges faced by the construction industry. Responding to those challenges imposes an urgent demand to raise productivity and quality, as well as incorporate new technologies to the industry. A lack of responsiveness can hold back development of the needed infrastructure for the construction industry and other activities in the country (Alarcon, 1994).

Pertaining to the challenges faced by the construction industry, numerous studies have been carried out in the past decades to identify the causes to the construction problems, and some of them have continued to suggest and recommend solutions to rectify those problems. The early phase of these studies mainly focused on the introduction of new technologies and equipment to speed up the construction process and improve overall productivity. However, it was only until late 1980s when a new construction improvement movement was being initiated in a more holistic and structured way based on the philosophy and ideology of lean production from Toyota Cooperation. Construction industry has then started to review and evaluate in the possibilities of implementing these lean production philosophies in the construction processes to optimize the overall performance in construction stage, as well as design stage. As a result, there has been a special interest in these philosophies in construction (Alarcon, 1994). This matter led to the question, that is whether or not they have implications for construction, and whether or not they have any significant impacts on the productivity improvement.

According to various studies in the field of Lean Construction (LC), the new production philosophy is laid on the concepts of conversion and flow in work processes. Therefore, the opportunity for performance improvement in construction can be addressed by adopting waste reduction strategies in the flow processes in parallel with enhancing production planning and control performance. This can be done through the utilization of new management procedures and tools with proper training and education programs. Unfortunately, these new ideas are not well understood by construction personnel. Particularly, waste is essentially considered as waste of materials in the construction processes while non-value adding activities such as inspection, delays, transportation of materials and others are not recognized as waste (Alarcon, 1995). In this context, poor production planning is considered as a particular cause for the occurrence of these non value-adding activities (Khanh, 2011). As a result, the productivity of construction industry cannot be improved due to the narrow interpretation on the concepts of waste, and the inappropriate procedures of production planning as well. The most suitable solution for this problem is that the knowledge and skills of all project parties should be increased through the substantial training and education programs in order to implement the new improvement strategies successfully in the construction processes (Tan, 2004).

1.2 Problem statement

Industry and construction are the most largest economic activity group accounted for proportion of 41.1% in GDP of Vietnamese economy (GSO, 2011). It is easily observed that this is due to Vietnam is a developing country. Many construction projects were performed to cater for the growing needs of population and economics in last decades. It is similar to other countries, especially developing countries, construction projects in Vietnam have faced many problems during implementation such as time and cost overrun, low partnering between project parties, lack of competency and skill of the labor force (Long, 2010), low productivity (Ho et al., 2007), lack of supply capacity (Luu et al., 2008), bureaucracy and low technological innovation (Nguyen et al., 2009), and poor production planning (Khanh, 2011), etc. These problems cause a considerable waste for construction projects; thus, they have been reducing success of project.

At present, LC is considered 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 (Ballard et al., 2002). Howell (1999) indicated that LC is similar to the current practice in the construction industry. Both practices pursue better meeting the customer needs while reducing waste of resources. In fact, while a few large construction companies have begun to look into waste reduction and process improvement issues through several concepts like LC, most organizations are yet to address these issues (Ramaswamy and Kalidindi, 2009).

Koskenvesa et al. (2010) have concluded that waste is not paid a lot of attention in the production planning and control processes, and it is considered as an accepted phenomenon in the Finnish construction industry. Furthermore, from a lean construction perspective, Memarian and Mitropoulos (2012) have claimed that the production control practices achieve an accelerated schedule while minimizing waste and maintaining high level of safety. Unfortunately, the traditional approach for planning production in construction industry frequently fails because it does not act over the difficulties related to input flows and also over the management of activities that normally do not aggregate value to the product such as transportation, waiting, and inspection (Conte, 1998).

On the basis of research in the 1990s, Ballard and Howell have created a concept in production planning and control called “Last Planner System” (LPS) to shield project from the uncertainty of work flows and to improve the predictability and reliability of construction production. Mossman (2012) indicated that LPS reduces waiting such as waiting for access, design information, materials and plant, waiting for the previous trade or design team to complete work. These are major sources of uncertainty, frustration and waste in projects. When one team is late delivering, follow-on teams are prevented from starting when they planned to and work ceases to flow. In fact, it is easily seen that a construction project performed by correct plans is more effective than the one executed by incorrect or poor plans. Therefore, construction wastes, e.g., waste related to waiting for others to complete their work, waiting for materials and equipment to be delivered on site, defects due to unclear design, over-allocation workers, and materials damaged or lost due to long-time inventory, can be explicitly reduced if production planning and control are well prepared.

1.3 Research objectives

It is presumably that the construction industry in Vietnam are also facing the problems of waste in construction projects. To date, there have not been many well-documented quantitative studies and reports that show the clear indicators to assess the extent of those problems. Therefore, examining applicability of the philosophies and tools of lean production is seen as a good opportunity to tackle the existing problems in the local construction industry.

The main goal of this study is to examine the current practice of waste problems in Vietnam construction industry (VCI) based on the philosophies and ideologies of lean production. This is meant to have a clearer picture on how "lean" is the local construction industry performed currently under the compilation of new measurement parameters especially in waste problems. It provides an important basis for the success of prospective implementation of LC in VCI. Therefore, three six objectives have been formulated to conduct this study are follows:

1. Examine general perception of the local construction professionals with the waste concepts in LC;
2. Identify main waste factors and their cause in current construction performance;
3. Investigate latent relationships between waste factors;
4. Determine "Waste Occurrence Level Indicators" (WOLI) for the construction industry;

5. Develop a model to predict the impact of waste factors on project performance cost;
6. Analyze the main waste factors that have strong impact on project performance cost.

1.4 Scope of research

LC is a popular philosophy used to manage project-based production in various countries such as United States, Brazil, Chile, Ecuador, England, Finland, Denmark and South Korea. Thus, there have been many philosophies and tools of LC developed to serve the demand of current practice in last decades. However, this study focuses mainly on the concepts and classification of wastes under the philosophies of lean production with high scrutiny.

The area of this study is confined to Ho Chi Minh City – the biggest and most dynamic city in Vietnam. The data are mainly collected through questionnaires that have been sent to the respondents by electronic mailing and internet survey link (a survey tool supported by Google) to selective group of respondents for the construction and consultant firms. The respondents are mainly people who have a leading role in the construction management, e.g., project managers, site managers, team leaders (QA, QC and QS), site engineers, supervisors, and foremen. Moreover, some case studies are adopted to validate or clarify the research problems.

The conducted sample surveys are not to be considered as a specific case in depth, but to capture the main characteristics of the population using a fixed sample. Thus, there is no limitation imposed to the level of qualification and working experience of the respondents. Moreover, the data collection is conducted from July 2012 to September 2012. Only the returned completed questionnaires that received during the designated period are analyzed, and the responses beyond this time frame are ignored.

1.5 Limitations of research

The explorative approach for this research is mainly based on structured surveys to be carried out based on questionnaires. Therefore, the feedbacks from the respondents provides as a sole dependable source of result in supporting the research findings. Field data collections for all the local construction projects help in verifying the feedbacks from the structured surveys. However, due to the time constraints and the insignificance of field data collections, they are discarded from the research design. It is recommended that further studies on this field should be carried out as collective efforts to justify the finding of this research.

As mentioned early, the new concepts about waste in lean production are not well-known categories in Vietnam, as well as many developing countries. Thus, there might be little attention given by the local construction industry to the area of parameters or variables that need to be measured and evaluated. This might affect the consistency of the results in the data measurement, where the subjectivity of answer from the respondents is required during collection.

1.6 Expected contributions

The study will make contributions from both academic perspective and practical perspective as follows:

- Academic perspective: the compilation of this research is intended to introduce the new philosophies of production applied in construction. Some quantitative assessments on the measurement of waste occurrence for local construction industry are made. In detail, it provides the new concepts of waste related to non-contributory and contributory time. Moreover, it helps to refine or reengineer the construction processes and practices, and provides a basis for the further development of studies in the field of LC in Vietnam.

- Practical perspective: The philosophies in designing, planning and controlling production of project between VCI and LC are quite similar because LC has been developed from the practice of project-based construction production. In this case, it is called "Lean Thinking" in construction. Although LC has been widely applied in many countries, many Vietnamese construction experts and managers questioned the feasibility of applying it in practice. Therefore, the study here reported is the first survey about lean thinking in the construction industry in Vietnam aiming to improve the current practice. Production weaknesses and problems of the industry will be redefined and reassessed in order to reformat a new strategy and plan for the efficiency improvement in the local construction practices.

1.7 Structure of thesis

The structure of this thesis has been designed to suit six distinct research's objectives above. The structure is orderly organized into six chapters. Table 1.1 presents the content summary for each chapter of thesis as below.

Table 1.1 Content summary for thesis's chapters

Chapter	Brief contents
1. Introduction	This chapter covers the overall perspective for the research including research background, problem statement, research objectives, scope of research, limitations of research, and expected contribution.
2. Philosophies of lean production	A literature review is done to scan and summarize the previous studies about the current problems of construction, the old and new concepts of production in construction, the philosophies and principles behind lean production, and the impact of lean production on construction efficiency.
3. Concepts and classification waste	This chapter will present traditional concepts of waste in construction, new concepts of waste under the philosophies of lean production, main causes for wastes, and discussion on waste problems in construction.
4. Research methodology	Short discussion about research methodology, the difficulties when conducting the study, and the reasons for applying the methodology are introduced. This chapter focuses on the questionnaire design, questionnaire distribution, data collection, and data analysis. Moreover, detailed introduction about analysis tools and methods are put in this chapter.
5. Analysis results	This chapter will focus on two tasks: • Present the findings of this study about waste problems in VCI that include: recognition and control of waste, correlation between recognition, control and frequency of waste, ranking of waste factors, ranking of waste causes, latent relationship between initial waste factors, evaluation of waste level for the construction industry, prediction model for effect of waste factors on project cost, identification of main cause for waste factors, and comparison between selected countries. • Some discussion and conclusions are made in the last section of this chapter.
6. Conclusions and recommendations	A general conclusion about the achievements of study and the brief conclusions for each research objective are presented. The detailed limitations and future research proposals are also pointed out at the end of this chapter

1.8 Summary

The study is conducted based on the criteria discussed above to examine the perception on waste concepts of professionals in VCI, as well as its impact on project performance cost. The further explanation for each of the subsequent chapters is summarized in Table 1.1 above.

CHAPTER 2

PHILOSOPHIES OF LEAN PRODUCTION

2.1 Introduction

This chapter aims to review the problems in construction, the trends in production improvement strategies for manufacturing and construction, the philosophies and principles behind lean production, new concepts of wastes and new process of production planning. Because traditional production approaches have revealed some weakness and shortcomings, major existing problems in construction are briefly described so as to understand why principles and tools of LC are needed in construction performance. Moreover, the applications of LC will be outlined to study the opportunity for creating improvement strategies in construction projects. Therefore, a literature review about studies related to LC principles, philosophies and techniques is mainly introduced and analyzed in this chapter.

2.2 Construction characteristics

Construction industry in many countries has been dominated by low performance in various aspects such as quality, safety, productivity and production delivery within planned budgets, methods and client satisfaction (Tan, 2004). Previous studies in the UK and Europe have indicated that maximum of 30% of construction is rework, potential labor efficiency is only 40-60%, accidents can count for 3-6% of total costs, and at least 10% of materials are wasted (DETR, 1998). The cost of rework in Australian construction projects has been reported as being up to 35% of total project cost, and contributes approximately 50% of a project's total overrun cost. In fact, rework is one of the primary factors that contribute to the poor performance and low productivity of the Australian construction industry (Love et al., 2003).

It is widely accepted that the construction industry is usually characterized by its complexities, reluctance to change and resistance to innovations (Oglesby et al., 1989). Furthermore, construction is inherent to risk, and its projects are generally unique and prototype (Kale and Arditi, 1999). Oglesby et al. (1989) pointed out that construction operates differently from other industries, and most construction projects are unique and fast-moving. In addition, the contractual structure in construction is seldom conductive to cooperation among participants. Moreover, Ballard and Howell (1998a) added two unique characteristics in construction including fixed position manufacturing and objects rooted in place.

In general, Kale and Arditi (1999) summarized several unique characteristics of the construction industry including fragmented industry structure, fragmented organization of the construction process, easy entry to the construction business, post-demand production, uniqueness of projects, high uncertainty and risk involved, high capital required for constructed facilities, and temporary nature of the relationships between parties. As a result, the construction industry requires more commitment of time, effort, talent and money (Oglesby et al., 1989).

2.3 Problems in construction

As mentioned early, the chronic problems of construction are well known as low productivity, poor safety, inferior working conditions, and insufficient quality (Koskela, 1993). However, most of the time, those critical problems of construction were left unattended because people of the industry refrained to believe or accept that there is a solution to those problems (Tan, 2004). According to Koskela (1992), the incapability to improve the productivity level of construction projects is mainly perceived by people in the industry due to its peculiarities and special features such as one-of-a-kind nature of projects, site production and temporary multi-organization. Especially, most people concluded that its fragmented nature, lack of co-ordination and communication between parties, adversative contractual relationships, and lack of customer focus have inhibited the performance of construction industry.

Different from manufacturing activities where the production activities are fundamentally supervised and controlled under a routine process, construction activities are subjected to relatively wide range of variability and waste factors throughout its information management and resource flow process. These variability and wastes generated in construction activities are mainly due to its large fieldwork component, the provisional nature of some of its organizations, and its intensive use of labor and non-stationary equipment. As a result, those construction peculiarities and variability will restraint the efficiency of the construction processes compared to those well-controlled stationary manufacturing processes. However, all of those peculiarities and variability can be overcome with the application of new flow design and improvements, as well as new technologies adoption (Alarcon, 1994). Therefore, the organization, planning, allocation and control of these resources, processes and technologies are what finally determine the productivity that can be achieved.

2.4 Trends in production improvement

2.4.1 Innovation in manufacturing

Throughout many decades, manufacturing has always been a reference point and a source of innovations to construction. Several efforts had been made to transfer the successful techniques and solutions from manufacturing process into construction in order to relieve the problems in construction industry. Most of the efforts involved new technology and process adoption from manufacturing practices, i.e., industrialized construction including prefabrication and modularization, computer integrated construction, and automated construction. These solutions have been seen as an important way to reduce fragmentation in construction, which is considered to be a major cause of existing problems. However, there have been no signs of major improvements to construction resulting from both trends of process dissemination and solutions as stated by Koskela (2000). The main reasons behind the failure of achieving major improvements from both trends are mainly due to the peculiarities and differences between manufacturing and construction (Khanh , 2011).

Currently, there is another development trend in manufacturing rather than information and automation technology. This trend stresses the importance of basis theories and principles related to production processes (Shingo, 1988; Schonberger, 1990; Plossl, 1991). Unfortunately, it was slowly caught the attentions of the academics and practitioners in construction industry until the end of 1980's. In the last three decades, performance in manufacturing has been greatly improved based on less on the manufacturing space, less on the human effort in factories, less on the investment in tools, and less on the product development time. In general, significant improvements in all performance indicators have been observed simultaneously in manufacturing industry. All these improvements have not been the product of a radical or sharp change of technology but the result of the application of a new production philosophy leading to “Lean Production” (Koskela, 1993).

These new development trends stress on the importance of basic theories and principles related to production management. Now, the same practices have been progressively promoted as an ideal solution in improvement strategies for construction industry especially in waste reduction and elimination strategies. Koskela (1992) identified the overwhelming dominance of conversion thinking in construction, and argued for replacing conversion model with a flow/ conversion model in order to reduce waste. Alarcon (1995) also pointed out that performance improvement opportunities could be addressed by adopting waste identification/ reduction strategies in parallel to value adding strategies. In other words, identifying and measuring waste will serve as an effective way to assess the performance of any production system because it will usually point out areas of potential improvement and the main causes of inefficiency.

Lean production in construction must come to grips with the entire design and construction process because increasingly complex projects are being urgently press forward under greater uncertainty. Field operations can be improved by using lean production principles but even they occur in a different context from manufacturing production. A comparison with manufacturing shows the key features, which distinguishes construction from manufacturing, is the extent of uncertainty evident throughout the production phase as shown in Table 2.1 (Howell and Ballard, 1994).

Table 2.1 Comparison between manufacturing and construction production (Howell and Ballard, 1994)

	Start of manufacturing production	Start of construction production
What	Highly defined	Evolving as means refines ends
How	Highly defined. Operations plan is in great detail based on many trails. Primary sequence of many tasks is inflexible and the interdependencies are documented and analyzed. Positions in process determine required skills	Partly defined but details un-examined. Extensive planning remains by hard logic but may change. Interdependencies due to conflicting measurements, shared resources, and intermediate products only partly understood. General craft skills to be applied in a variety of positions
Assembly objectives	Produces one of a finite set of objects where details of what and how are known at the beginning of assembly	Make the only one. The details of what and how are not completely known at the beginning of assembly
Improvement strategy	Rapid learning during the first units preparing for production line	Rapid learning during both planning and early sub-assembly cycles

2.4.2 Production philosophy in manufacturing

Traditional manufacturing production philosophy and practices from the earlier days of industrialization period have never gone beyond the concept of the overall production process to be treated as a mean of transformation process only, and ignoring the flow process has limited the full potential of process improvement. In 1950's, those traditional manufacturing production systems were set for a paradigm shift when Taiichi Ohno (1912-1990), a former Toyota executive, has set out to develop a new production system, called Toyota Production System (TPS). Ohno's original ideas were based on the adoption of production strategies identified according to the demand of the downstream production chain that ensures the planned pace is maintained throughout the production process.

The basic idea in the TPS is the elimination of inventories and other wastes through small lot production, reduced set-up times, semiautonomous machines, co-operation with suppliers and other techniques. In other words, the idea is to achieve a continuous production flow by adopting monitoring measures for each process phase and aiming to reduce inventories (Conte and Gransberg, 2001). The production philosophy behind TPS is called Just-in-Time production (JIT). Throughout the years, it has remained among the core practices of the new production philosophy. Big productivity gains from JIT production and later as lean production had been reported from manufacturing since the end of 1970's (Koskela, 2000).

Simultaneously, quality issues were attended by Japanese industry under the guidance of American consultants like Deming, Juran and Feigenbaum. Quality philosophy evolved from a statistical method of quality assurance to a wider approach including quality circles and other tools for further development of companies. These ideas were developed and refined by industrial engineers in a long process of trial and error. However, establishment of theoretical background and wider presentation of the approach has not been seen as necessary.

However, these ideas on new production philosophy were not widely employed around the industry at the beginning stage, they only diffused to Europe and America starting in about mid 1970, especially in the automobile industry. Since the end of 1970's, a lot of new approaches to production management have been introduced into manufacturing industry, i.e., JIT, Total Quality Management (TMQ), Time-Based Competition, Value-Based

Management, and Concurrent Engineering. It turned out that these approaches have the same common idea that helps to gradually improve the production efficiency.

The general conception of the new production philosophy evolved through three levels: (1) as a tool (e.g., kanban and quality circles), (2) as a manufacturing methodology (e.g., JIT and TQM), and (3) as a general management philosophy (e.g., lean production) (Koskela, 1993). This common idea, in general, is shared by a conceptualization of production or operations. The difference in view angle is determined by the design and control principles emphasized by a particular approach. For instance, JIT stresses the elimination of waiting times; whereas TQM aims at the elimination of errors and related rework, but both of them are applied under the same conceptualization of production and operation, e.g., a flow of work, material or information.

In the beginning of the 1990's, lean production became an emerging mainstream approach. It is partially practiced by major manufacturing companies in Japan, United States, and Europe. The new approach has also diffused to new fields such as customized production, services, administration, and product development. In recent years, this new production philosophy has been disseminated in other industries in general, and in construction industry in particular (Koskela, 2000).

The latest development on new production philosophy is closely integrated with the ideology of lean thinking aiming for a leaner production chain throughout every stage of the processes. The term "lean" refers to a general way of thinking and specific practices that emphasize less of everything, i.e., fewer people, less time, and lower cost (Cusumano and

Nobeoka, 1998). Womack and Jones (1996) suggested that lean thinking provides a way of specify value, lines up value-creating actions in the best sequence, conducts activities without interruption whenever someone requests them, and performs these activities more effective. Freeman (1999) concurred that lean thinking is not just about cutting down wastes (wasted time, wasted effort and wasted materials), but also about putting on value. It involves focusing on the whole process from early design to final handover. However, Liker (2004) stated that lean thinking requires employees to change the way they view and execute their work. It is a willing to learn, to work better and strive for continuous improvement.

2.5 New philosophy in production

2.5.1 General background

The core of the new production philosophy is based on the conclusive understanding that all production systems are constituted of two main activities: conversions and flows (waiting, moving, and inspecting). In the new production paradigm, only conversion activities add value to the final product, whereas flow activities do not. Value is determined under the value stream of the customers with the satisfaction of their requirements and cost paid on the final product. Therefore, the primary objectives for process improvement under the new production philosophy should be targeted separately. That can be done through the improvement of flow activities by primarily focusing on reducing or eliminating them and conversion activities should be focused on making them more efficient.

This has important implications for the design, control and improvement of production processes, because according to Koskela (1992), traditional production management paradigm sees the whole process simply as a conversion of an input into an output that can be divided into sub-processes. All activities have been treated as value-adding conversions without separating from the flow processes. This has led to complex, uncertain and confused flow processes, expansion of non value-adding activities, and reduction of output value.

The conception of the new production philosophy is evolved by three stages: (1) viewed as a tool like kanban and quality circles, (2) viewed as a manufacturing method like JIT, and (3) viewed as a general management philosophy (referred to lean production) (Koskela, 1993; Koskela and Leikas, 1994). Eaton (1994) stated that a generic process improvement plan can be derived from new production philosophy. The first step to implement process improvement plan is by analysis and separation of conversions and flows activities. For conversions activities identified, those activities should be channeled into the quality cycles (Quality Control, Quality Assurance, and TQM) to increase efficiency of value-added conversions. Whereas, for flow activities, the approach should consist of way of flow simplification in order to reduce or eliminate non-value added flow activities.

2.5.2 Concepts of production

A historical analysis carried out by Koskela (2000) has revealed that there are three concepts of production where the conceptualization of production can be grouped based on the generation of transformation-flow-value (TFV) model of production theory.

2.5.2.1 Transformation concept

Since the beginning of the 20th century, transformation concept has been the dominant theory of production both in practice and research, where production is conceptualized as a process of transformation or "a transformation of inputs to outputs". Production management equates to decomposing the total transformation into elementary transformations and tasks, acquiring the inputs to these tasks with minimal cost, and carrying out the tasks as efficiently as possible.

The first principle which has been used in conjunction with transformation concept stated that the transformation process can be decomposed into sub-processes as described in Figure 2.1. The main purpose of this action is to break down the total transformation task into individual continual tasks.

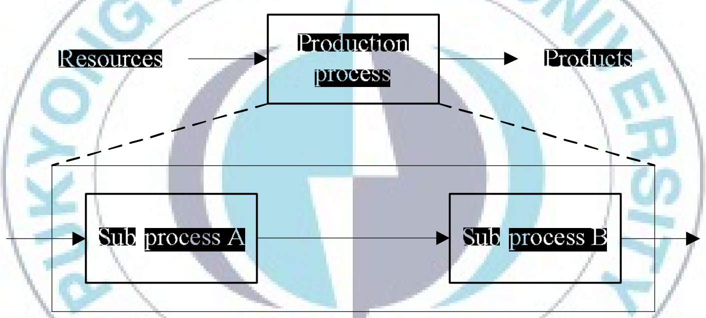


Figure 2.1 Decomposition of production process (Koskela, 2000)

The second principle of the transformation model is a general acceptance of independency principle that the cost of the total process can be minimized through minimizing the cost of each sub-process. The key issue pertaining to this principle leads to the assumption that every sub-process of a total process are independent from each other, therefore cost minimization can be applied through focusing on cost management in each operation, sub-process or department.

The third principle is to insulate the production process from the external environment through physical or organizational buffer. This principle is related to the independence assumption from the second principle as discussed above. It reflects that the transformation process is the most important process. Thus, it is a requisite to shield the production from the erratic conditions in the environment.

2.5.2.2 Flow concept

The flow view of production has provided the basis for JIT and lean production. This view was translated into practice by Ford (1926). However, the template provided by Ford was misunderstood, and only from 1940's onwards the flow view of production was successfully developed in Japan at Toyota cooperation. In flow concept, production is viewed as a flow, where there are waiting, inspection and moving stages between transformations. Production management tends to minimize the share of production flow especially in reducing variability. In this context, flow model is looking beyond transformation model by taking non-transformation activities into consideration to improve overall flow efficiency.

The first principle of flow concept is that time is considered as an input of production. Therefore, the main focus is amount of time consumed by the total transformation and its parts by aiming to the production improvement at shortening of the total time.

The second principle of flow concept is that time is consumed by two types of activities in the overall production flow which are transformation activities and non-transformation activities. Koskela (2000) categorized the non-transformation activities into transfer, delay and inspection. It is obviously that these non-transformation activities are unnecessary; thus, the less of them is better. Figure 2.2 shows the process of production flow.

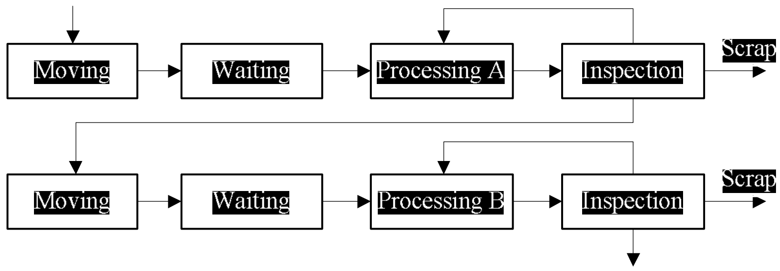


Figure 2.2 Process of production flows (Koskela, 2000)

2.5.2.3 Value concept

The value generation view is formulated by incorporating customer's value to the production. Thus, the goal of production is to satisfy customer needs. In this case, value generation concept covers external needs and internal physical production process. Figure 2.3 illustrates the conceptual scheme of a supplier-customer pair. It is easily seen that it is not the transformation itself that is valuable, but the output corresponds to the requirements and wishes of the customer which is valuable instead.

This concept views production as a mean for fulfillment of customer needs. In this situation, production management is to accurately translate these needs into a design solution, and then create products that conform to the specified design. It focus on control of the transformation and flow in securing value generated for the customer.

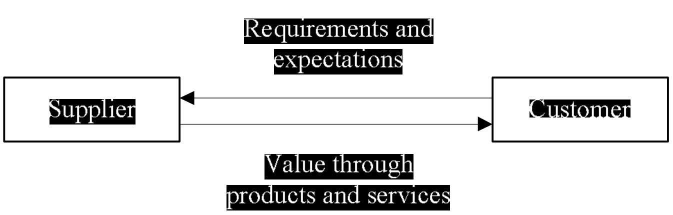


Figure 2.3 Conceptual scheme of supplier-customer pair (Koskela, 2000)

Koskela and Leikas (1994) indicated that the goals of flow process, in nature, are to decrease process cost and duration, and to increase value for the customers. The value consists of two components: production performance and freedom from defects. Value has to be evaluated from the perspective of the final customer. However, measuring the relative value often suffices for practical application, e.g., the value loss in relation to the best practice value or theoretically best value.

2.5.3 Main ideas and techniques of lean production

2.5.3.1 Just-in-Time (JIT)

The starting point of the new production philosophy was in industrial engineering initiated by Ohno and Shingo at Toyota cooperation in the 1950's. The driving idea in the approach was reduction or elimination of inventories (work-in-progress). In turn, this led to establish other techniques that were used to cope with fewer inventories: lot size reduction, layout reconfiguration, supplier cooperation, and set-up time reduction. The pull production control method, where production is initiated by actual demand rather than by plans based on forecasts, was introduced.

The concept of waste is one cornerstone of JIT. The following seven wastes were recognized by Shingo (1981) as follows: (1) overproduction, (2) waiting, (3) transporting, (4) too much machining (over-processing), (5) inventories, (6) moving, (7) making defective parts and products. Elimination of waste through continuous improvement of operations, equipment and processes is another cornerstone of JIT.

2.5.3.2 Total quality control (TQC)

The starting point of the quality movement was the inspection of raw materials and products using statistical methods. The quality movement in Japan has evolved from mere inspection of products to total quality control. The term “total” refers to three extensions:

1. Expanding quality control from production to all departments;
2. Expanding quality control from workers to managers;
3. Expanding the notion of quality to cover all operations in the company.

The quality methodologies have developed in correspondence with the evolution of the concept of quality. The focus has changed from an inspection orientation (sampling theory) through process control to create continuous improvement, and to design quality into the product.

2.5.3.3 Other related techniques

Many new concepts and techniques have surfaced from JIT and TQC efforts. Most of them have same underlying ideas in improving production efficiency. These concepts are described below.

- **Total productive maintenance**

Total Productive Maintenance (TPM) originated in Japan in 1971 as a method for improved machine availability through better utilization of maintenance and production resources. In most production settings, the operator is not viewed as a member of the maintenance team. Whereas, in TPM, the machine operator is trained to perform many of the day-to-day tasks of simple maintenance and fault-finding. Teams are created that include a technical expert (often an engineer or maintenance technician) as well as operators. In this setting, the operators are enabled to understand the machinery and identify potential problems, righting them before they can impact on production and by so doing, decrease downtime and reduce costs of production.

TPM is a critical adjunct to lean manufacturing. If machine uptime is not predictable and if process capability is not sustained, the process must keep extra stocks to buffer against this uncertainty and flow through the process will be interrupted. Unreliable uptime is caused by breakdowns or badly performed maintenance. Correct maintenance will allow uptime to improve and speed production through a given area allowing a machine to run at its designed capacity of production .

TPM tackles the "six big losses" in production process. It is closely tied to the practices of 5S (Sort, Set, Shine, Standard, and Sustain). They are the followings:

1. Breakdown losses
2. Setup and adjustment losses
3. Idling and minor stoppages
4. Reduced speed losses
5. Start up losses
6. Quality defects

- **Concurrent engineering**

Concurrent Engineering is a work methodology based on the parallelization of tasks, which helps to perform tasks within the same time frame. It refers to an approach used in product development in which functions of design engineering, manufacturing engineering and other functions are integrated to reduce the elapsed time required to bring a new product to the market. Therefore, cost of constructability, customer needs, quality issues, and product life cycle cost are taken into account earlier in the development cycle.

The main idea about concurrent engineering is to achieve an improved design process characterized by analyzing rigorous up-front requirements, incorporating the constraints of subsequent phases into the conceptual phase, and tightening of change control towards the end of the design process.

- **Continuous improvement process**

Continuous Improvement Process (CIP) is never-ending efforts to expose and eliminate root causes of problems. A continuous improvement strategy involves everyone from the bottom to the top. The basic premise is that small regular improvements lead to a significant positive improvement over time. Delivery processes are constantly evaluated and improved in the light of their efficiency, effectiveness and flexibility.

The main goal of the continuous improvements is to affect the mindset as well as achieve the improvements of the techniques. In this case, everyone receives training in the appropriate skills. They are then responsible for areas and progress of their team. The employees will continuously suggest improvements to meet quality and cost, and to delivery target improvements. The key idea of continuous improvement is to maintain and improve the working standard through small and gradual improvements.

- **Visual management**

Visual Management (VM) is an orientation towards visual control in production, quality and workplace organization. The core principal of VM is the ability that if production is ahead, on par or behind, what needs to be done next. No orders are missed or lost, and everyone knows if they are behind or ahead on the expected production's day.

VM is a business management technique employed in many places where information is communicated by using visual signals instead of texts or other written instructions. The design is deliberate in allowing quick recognition of the information being communicated in order to increase efficiency and clarity.

- **Reengineering**

Reengineering is the radical reconfiguration of processes and tasks, especially with respect to implementation of information technology. The key issue in reengineering is the recognition and elimination of outdated rules and assumptions in order to establish a radical change to the processes and tasks for improvement. Michael and James (1993) defined reengineering as fundamental rethinking and radical redesign of business process to achieve dramatic improvements in critical measures of performance such as cost, service, and speed.

- **Value-based management**

Value-Based Management (or strategy) is a customer-oriented approach, in contrast to competitor-oriented approach, towards overall production process. It is a continuous improvement to increase customer's value by conceptualizing and articulating value as the basis for competition.

2.5.4 Principles of lean production

In various subfields of the new production philosophy, a number of heuristic principles for flow process design, control and improvement have evolved. According to Koskela (1993), there were some evidence that show the efficiency of flow processes in production activities can be considerably and rapidly improved through these principles. Some of them are related to theory orientation, while others are related to application orientation. There are three types of principles of new production including flow compression (see Table 2.2), flow dynamic and flexibility (see Table 2.3), and flow stability and control (see Table 2.4) (Koskela, 1992).

Table 2.2 Description of the principles of flow compression

#	Principle	Description
1	Reduce the share of non-value adding activities.	Since a task is divided into two subtasks which executed by different specialists, non-value adding activities increase due to inspecting, moving and waiting. Many processes have not been designed in an orderly form in administrative field, and the nature of the production is work-in-process moved from one conversion to the next, therefore, defects emerge, accidents happen.
2	Increase output value through systematic consideration of customer requirements.	Carrying out a systematic flow design, where customer are defined for each stage, and their requirements analyzed. Especially enhanced transparency and continuous improvement.
3	Reduce variability in the processes.	Decreasing variability is made up of the well-known procedures of statistical control theory. Especially in dealing with measuring variability, then finding and eliminating its root causes.
4	Reduce the cycle time.	Eliminating work-in-process; reducing batch sizes; changing plant layout; keeping smoothing flows; reducing variability; changing activities from sequential order to parallel order; isolating the main value-adding sequence; and decrease organizational layers and empowering the persons working directly within the flows.

Table 2.3 Description of the principles of flow dynamic and flexibility

#	Principle	Description
1	Simplify by minimizing the number of steps and parts.	Simplification can be understood as reducing of the number of components in a product and steps in a material or information flows. There are some approaches such as shortening the flows by consolidating activities; reducing the part count of products through design changes or prefabricated parts; standardizing parts and materials; decoupling linkages; and minimizing the amount of control information needed.
2	Increase output flexibility	Increasing flexibility include minimizing lot sizes to closely match demand; reducing the difficulty of setups and changeovers; customizing as late in the process as possible; and training a multi-skilled workforce.
3	Increase process transparency	Establishing basic housekeeping to eliminate clutter by 5-S method (sort, set, shine, standard and sustain); making the process directly observable through appropriate layout and signage; rendering invisible attributes of the process visible through measurements; embodying process information in work areas, tools, containers, materials and information systems; utilizing visual controls to enable any person to immediately recognize standards and deviations; and reducing the interdependence of production units.
4	Focus control on the complete process	The complete process has to be measured and controlled tightly. In hierarchical organizations, process owner for cross-functional processes are appointed with responsibility for the efficiency of that process. Further, long-term cooperation with suppliers and team building should be taken to get the goal of deriving mutual benefits from an optimized total flow.

2.6 Flows in construction production

The production in construction is one of assembly production types, where different material flows are connected to the final product. In construction, there are three types of flows include material flow (e.g., the transportation of components to the site for particular installation), location flow (e.g., one particular trade goes through the different part of the building or construction site to get their work done) and assembly flow (e.g., the sequential of works of assembly and installation) (Koskela, 2000).

Table 2.4 Description of the principles of flow stability and control

#	Principle	Description
1	Build continuous improvement into the process	There are several necessary methods for a continuous improvement such as measuring and monitoring improvement; setting stretch targets by means of which problems are unearthed and their solutions are stimulated; giving responsibility for improvement to all employees and a steady improvement from every organizational unit should be required; using standard procedure as hypotheses of best practice; and linking improvement to control the current constrains and problems of the process.
2	Balance flow improvement with conversion improvement	The potential for flow improvement is usually higher than conversion improvement. In other words, flow improvement can be started with smaller investments, but usually requires a longer time than a conversion improvement. To obtain that improvement, the conversion requirements should be adjusted or the new technology should be applied.
3	Benchmark	Assessing the strengths and weaknesses of sub-processes; knowing the industry leaders or competitors; gaining superiority by combining existing strengths and the best external practices, catching timely the trend of market.

There are seven resource flows that unite to generate the construction task as illustrated in Figure 2.4. Many of these resource flows characterize high variability; thus, the probability of a missing input is considerable. For instance, it is not uncommon that detailed drawings are still lacking at the intended start of the work. Latent errors in drawings will emerge as problems during construction on site. External conditions also form one specific source of variability. The productivity of manual labor is inherently variable, and the availability of space and connecting works is dependent on the progress of tasks of previous trades. Thus, in comparison to the typical manufacturing, construction production is subjected to more sources of variability, and the insight gained is that construction consists of assembly tasks involving a high number of input flows. Planning and controlling production become a very important task, and flow management has to be considered in parallel with production management (Koskela, 2000).

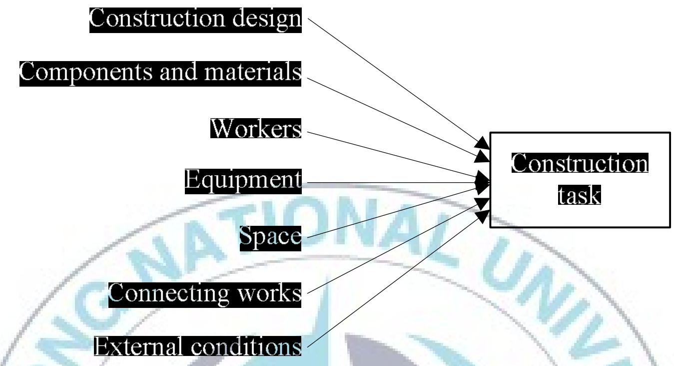


Figure 2.4 The preconditions for a construction task (Koskela, 2000)

In construction, production is conducted by a installation team that moves from location to location. This leads to another important feature of construction. In industrial production, one part can physically be only at one workstation at any one time. However, in construction, several work units or trades can simultaneously work on one part at the same time with lessened productivity due to interference and congestion of space of operation. Thus, this phenomenon of congestion has a more dramatic influence on construction productivity especially at workstation congestion which is the common problem in manufacturing.

Serpell et al. (1995) have proposed a dynamic construction process model including internal flows and external flows as described in Figure 2.5. The model presents the production process on which work has been based on a system that correlated with the environment around it. This is an open and dynamic system inside an environment that conditions its status and behavior. Part of the environment is controllable by the system but other factors are outside of its control.

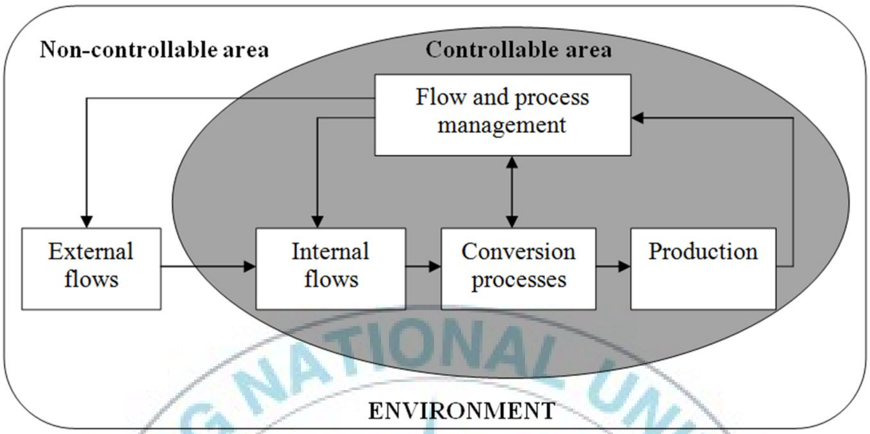


Figure 2.5 Model of the construction process (Serpell et al., 1995)

2.7 Comparison between old and new production philosophy

The conventional production philosophy is only based on transformation concepts while the new production philosophy is based both flow concepts and value generation concepts in the development of production system. The most significant differences between two philosophies can be discussed in two areas: conceptualization of production, and focus of improvement.

For the conventional production philosophy, production is perceived as consisting of conversions only with all the activities in the processes regarded to value adding, and the focus of process improvement will only happen by implementing new technology into the activities. Whereas, for new production philosophy, production is perceived as consisting of conversions and flows, where activities in the processes can be divided into value adding and non-value adding activities. Therefore, the focus of process improvement can be broken down into two separated areas, which are the elimination or reduction for non-value adding activities and the increase of process efficiency for value adding activities through continuous improvement and new technology (Koskela, 2000; Koskela and Leikas, 1994). The detailed description of this improvement strategy is shown in Figure 2.6.

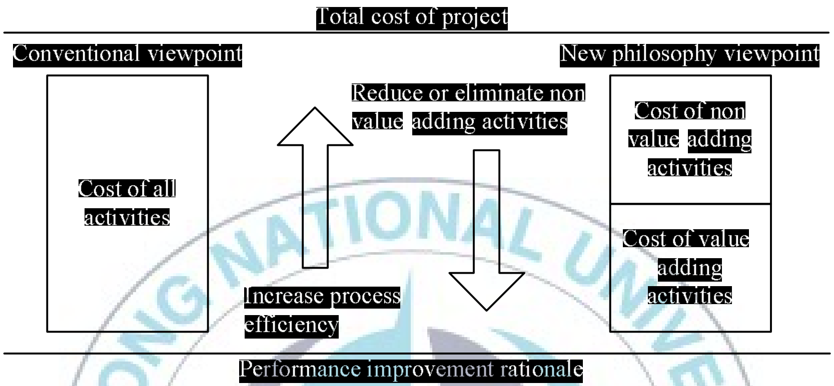


Figure 2.6 Comparison between the conventional and new philosophy viewpoint (Simplified from Koskela, 2000)

2.8 The impact of new production philosophy

In reality, production processes of construction are characterized by high volume of non value-adding activities that lead to low productivity. Thus, the development of methods for process improvement, as well as the introduction of new production philosophies which contemplate continuous improvement, can have an important impact on management, productivity, quality, and technologies. The potential for improvement is tremendous, and proof of this are the results obtained in the automotive industry, where impressive reductions have been achieved in the use of each of the components in the productive processes (Alarcon, 1994):

- Reduce 50% in human labor

- Reduce 50% in assembly space
- Reduce 50% in investment in tools
- Reduce 50% in engineering hours

In recent years, application of new philosophy in construction are getting more and more popular especially in the developed countries such as US and countries in Europe. Lauri Koskela, Gregory Howell, and Glen Ballard are the pioneers in creating the concept of "Lean Construction" by seeing the potential for applying the general principles into construction (Wright, 2000). According to the definition of Lean Construction Institute, LC is a production management-based approach to project delivery. It is considered as a new way to design and build capital facilities and it extends from the objectives of a lean production system to maximize value and minimize waste. Until now, the enthusiasms over lean construction paradigm are intensified and widely accepted by practitioners and academics around the world under the belief that the implementation of LC will dramatically improve construction performance and labor productivity.

The basis of promoting a continuous improvement in productive processes is through a reduction of "waste" (time, cost, rework and accidents) and an increase in "value". Based on the report of Department of the Environment, Transport and Regions (DETR, 1998) in UK, the impacts of whole LC principles and techniques in construction industry are:

- Reduce capital costs by 10%
- Reduce construction time by 10% (time from client approval to practical completion)
- Improve predictability by 20% (number of projects completed on time and within budget)

- Reduce defects on handover by 20%
- Increase productivity by 10% (in value added per head)
- Increase profits and turnover by 10%
- Reduce accidents in site by 20%

2.9 Summary

This chapter has introduced: some current problems occurring in construction, trends in innovating improvement strategies for manufacturing production, new philosophies in production, new concepts of production, principles and tools behind lean production.

It is important to remind again that there is no implementation of any tool and technique of LC in VCI until now, but there are the same philosophies between them because the construction industry in Vietnam has been applying and developing some new methods for enhancing the efficiency of project performance. Furthermore, according to the literature above, the principles of LC is applicable to VCI. Thus, conducting a study to examine the current practice of the construction industry about lean thinking is needed and urgent. The strategy to improve efficiency through reducing the wastes can be then made based on the research's findings.

CHAPTER 3

CONCEPT AND CLASSIFICATION OF WASTE

3.1 Introduction

Wastes, also known as non value-adding activities, are key challenges being faced by construction industry for a long time. Therefore, numerous studies have been carried out to identify the causes of waste problems. Some new technologies and equipment were introduced to speed up the construction process and improve overall productivity (Tan, 2004). These technologies were based on the philosophies and ideologies of lean production in Toyota Production System (TPS), (Ohno, 1988). However, there were some different viewpoints between TPS and construction field; thus, before applying the philosophies of TPS to construction industry, its peculiarities must be found out thoughtfully. These can make many different methods for lean thinking in construction management.

Many previous studies have demonstrated that significant amounts of project values have been lost due to weak project management, defective design, poor quality of work, inferior working conditions, poor safety arrangement, etc (Koskela, 1993). These chronic problems have created the wastes for the amount that the owner has been actually paying to complete the project as planned (Khanh, 2011). Nowadays, lean construction has been considered as an opportunity to tackle the prevailing problems of waste in construction industry and to estimate the impacts of waste on the overall project performance (Ali, 2008). Unfortunately, the new concepts of lean construction, especially in waste and value loss of time, have not been well understood by construction personnel. Particularly, the construction personnel often think that wastes are generally associated with waste of materials in the construction processes while non value-adding activities such as inspection, delays, transportation of materials, and others are not recognized as wastes (Alarcon, 1995). Therefore, reducing the share of non value-adding activities is one of the core strategies for construction productivity improvement (Zhao and Chua, 2003).

This chapter will present traditional concepts of waste in construction, new concepts of waste under the philosophies of lean production, main causes for wastes, and discussion on waste problems in construction.

3.2 Overview of waste problems

3.2.1 Traditional concepts of waste

Waste in the construction industry has been the subject of several research projects around the world in recent years. However, most studies tend to focus on the waste of materials, which is only one of the resources involved in the construction process. This seems to be related to the fact that most studies are based on the conversion model, in which material losses are considered to be synonymous of waste. Formoso et al. (2002) stated that many people in the industry have considered waste are directly associated with the debris removed from the site and disposed of in landfills. They suggested that the main reason for this relatively narrow view of waste is perhaps the fact that it is easy to see and measure. Therefore, the concepts of waste are seen to be restricted to physical wastes or material wastes in construction projects.

There is a very high variability of waste indices from site to site. Furthermore, similar sites might present different level of wastes for the same materials. This indicates that a considerable portion of this wastage can be avoided. Currently, some companies do not seem to be concerned about material waste, since they do not apply relatively simple procedures to avoid waste on site. None of them had neither a well-defined material management policy nor a systematic control of material usage. Therefore, most causes of waste are related to flaws in the management system, and to lack of knowledge about waste (Khanh, 2011).

Koskela (1993) has conducted a study to indicate the order of magnitude of wastes on various partial studies carried out in Sweden and US. It has shown that construction processes are characterized by high content of wastes leading to low productivity (see Table 3.1).

Table 3.1 Level of waste in construction (Koskela, 1993)

Waste	Total	Country
Non-conformance quality costs	12%	US
External quality cost during facility use	4%	Sweden
Lack of constructability	6-10%	US
Poor materials management	10%	US
Excess consumption of materials on site	10%	Sweden
Working time used for non-value adding activities on site	67%	US
Lack of safety	6%	US

In the effort to search for the waste and loss of value in current construction practices, Koskela (1992) has presented a few evidences from various studies around the world apart from the material waste from conversion activities. This study has looked for the evidence of waste due to poor quality of works, gaps in material management, non-productive time, inadequate safety program, and lack of constructability.

3.2.2 New concepts of waste

In new production philosophy, “waste” has been given a broader concept and definition as compared to its usual narrow meaning. It should be understood as “*any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building*”. Waste includes both the incidence of material losses and the execution of unnecessary work, which generate additional costs but do not add value to the product (Koskela, 1992).

Three other definitions deeply expressed the broaden dimension of wastes as follows:

- Toyota Cooperation: “Anything that is different from the minimum quantity of equipment, materials, parts and labor time that is absolutely essential for production.”
- Alarcon (1995): “Anything different from the absolute minimum amount of resources of materials, equipment and manpower that is necessary to add value to the product.”
- Formoso et al. (1999): “Any loss produced by activities that generate direct or indirect costs, but do not add any value to the product from the point of view of the client.”

In general, lean production assumes all activities that produce cost, both direct and indirect cost, but do not add value to the product can be called waste. In this context, waste is measured in terms of project costs. Other types of waste are related to the inefficiency of the processes. These wastes are more difficult to be measured because the optimal efficiency of a process is not always known.

3.2.3 Classification of wastes

Many researchers and practitioners have indicated that there are many non-value adding activities during the design and construction process, and majority of those wasteful activities consume time and effort without adding value for the client. Since the beginning of a construction project, project managers have to deal with many factors that may negatively affect the construction process (Serpell et al., 1995). Moreover, they have stated that waste in construction and manufacturing include delay times, quality costs, lack of safety, rework, unnecessary transportation trips, long distances, improper choice of management, methods or equipment, and poor constructability (Alarcon, 1993; Koskela, 1992; Serpell et al., 1995).

Regarding the possibility to control the incidence of waste, Formoso et al. (1999) commented that there is an acceptable level of waste, which can only be reduced through a significant change in the level of technological development. Based on the ratio of prevention investment cost over the cost of waste itself, they have classified wastes into two general groups: (1) unavoidable waste (or natural waste); and (2) avoidable waste.

Waste can also be classified according to its origin, i.e., the stage that the main root cause is related. Although waste is usually identified during the production stage, it can be originated by processes that precede production, such as materials manufacturing, training of human resources, design, materials supply, and planning. However, the most classical waste classification according to lean production paradigm is perhaps the classification done by Shigeo Shingo in 1981 as follows:

1. Waste due to overproduction
2. Waste due to wait periods
3. Waste due to transport
4. Waste due to system itself
5. Waste due to stock
6. Waste due to operation
7. Waste due to defects

Based on Shingo's seven wastes above, Formoso et al. (1999) went on to propose their main classification of waste based on the analysis of some Brazilian building sites as shown below. It was thought that the further classification would help managers to understand the different forms of waste, i.e., why they occur and how to act in order to avoid them.

1. *Overproduction:* It is related to the production of a quantity greater than required or earlier than necessary. This may cause waste of materials, man-hours or equipment usage. It usually produces inventories of unfinished products or even the loss in the case of materials that can deteriorate.
2. *Substitution:* It is monetary waste caused by the substitution of a material by a more expensive one (with an unnecessary better performance); or the substitution of an execution of simple tasks by an over-qualified worker; or the use of highly sophisticated equipment where a much simpler one will be enough.
3. *Waiting time:* It is related to the idle time caused by lack of synchronization and leveling of material flows, and pace of work by different groups or equipment.
4. *Transportation:* It is concerned with the internal movement of materials on site. Excessive handling, use of inadequate

equipment or bad conditions of pathways can cause this kind of waste. It is usually related to poor layout, and the lack of planning of material flows. Its main consequences are: waste of man-hours, waste of energy, waste of space on site, and waste of material damages during transportation.

5. *Processing:* It is related to the nature of the processing (conversion) activity, which could only be avoided by changing the construction technology.
6. *Inventory:* It is related to excessive or unnecessary inventories which lead to material waste (deterioration, losses due to inadequate stock conditions on site, robbery, vandalism), and monetary losses due to the capital that is tied up. It can be a result of lack of resource planning or uncertainty on the estimation of quantities.
7. *Movement:* It is concerned with unnecessary or inefficient movements made by workers during their job. This can be caused by inadequate equipment, ineffective work methods, or poor arrangement of the working place.
8. *Defective products:* It occurs when the final or intermediate product does not fit the quality specifications. This may lead to rework or to the incorporation of unnecessary materials. It can be caused by poor design and specification, lack of planning and control, poor qualification of the team work, lack of integration between design and production, etc.
9. *Others:* They are wastes of any nature different from the previous ones such as burglary, vandalism, inclement weather conditions, accidents, etc.

Serpell et al. (1995) have proposed five waste categories of non-productive time as shown in Figure 3.1. They highlighted some limitations to the waste classification of non-productive time. For example, the waste of time due to slow work is related to the efficiency of processes, construction equipment and personnel. But it is difficult to measure it because it is first necessary to know the optimal efficiency that can be achieved, which is not always possible.

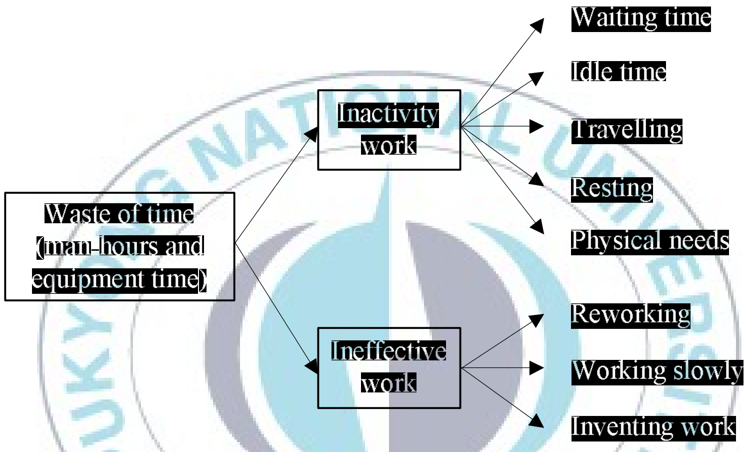


Figure 3.1 Categories of wastes of productive time (Serpell et al., 1995)

Instead of classifying the waste according to non-productive time, Serpell et al. (1995) have continued a further step to break down those waste factors in relation of work categories. There are three types of work categories as below:

1. Productive works: They are activities that add value to product
2. Contributory works: They are activities that do not add value to product but they are essential for conversion process including transporting, instruction, measuring, cleaning and others.

3. Non-contributory works: They are activities that do not add value to product and they are not essential for conversion process including waiting, idle time, travelling, resting, physical needs and rework.

3.2.4 Main causes of waste

After understanding the classification of waste, it is important to examine the type of possible causes that lead to the occurrence of waste in construction process. This is an important step because by knowing the cause of waste will help to monitor the wastes well. Therefore, to work out a continuous improvement strategy in reducing and eliminating the wastes in construction processes, the origin of the waste has to be identified.

A typical waste identification survey underlined a few examples of waste sources according to different area of functions such as administration, use of resources, and information systems. Several potential sources of waste can be grouped under the particular area of functions, and it can be created to suit the need of particular projects. Alarcon (1994) listed down the following group of potential sources of waste in construction projects:

1. Administration group: It includes unnecessary requirements, excessive control, lack of control, poor planning and scheduling, and bureaucracy.
2. Use of resources: It includes surplus, shortage, misuse, poor distribution, poor quality, and poor availability.
3. Information system: It includes unnecessary system, defective system, late system, and unclear system.

On the other hand, Serpell et al. (1995) have identified several controllable causes of waste. Although they mainly concentrated on wasted time but the classification of the causes for waste was more structured and detailed compared to other studies. They divided the controllable wastes into three different activities, which are associated with flows, conversions, and management activities.

1. Controllable causes associated to flows
    a. Resource:
        - Materials: Lack of materials at the work place, poor material distribution, and inadequate transportation means.
        - Equipment: Non-availability, inefficient utilization, and inadequate equipment for work needs.
        - Labor: Attitudes of workers, and stoppage of work.
    b. Information: lack of information, poor information quality, and inadequate timing of delivery.
2. Controllable causes associated to conversions
    a. Methods: Deficient design of work crews, inadequate procedures, and inadequate support to work activities.
    b. Planning: Lack of work space, too much people working in reduced space, and poor work conditions.
    c. Quality: poor execution of work, and damages to work finished.
3. Controllable causes associated to management activities
    a. Decision making: Poor allocation of work to labor, and poor distribution of personnel.

b. Ineffective supervision or control: Poor or lack of supervision during performance.

3.3 Discussion on waste problems

Construction wastes investigated in this research are defined and classified by LC philosophies. The execution of unnecessary works that generate additional costs but do not add value to the product is considered as wastes (Koskela, 1992). Measuring waste is an effective way to assess the performance of production systems but very few studies have been conducted to examine all waste categories in a construction process (Ramaswamy and Kalidindi, 2009). However, studies from various countries in which different aspects of waste have been quantified give an indication of the order of the magnitude of wastes in construction. These aspects are often cost, time, materials and manpower for construction activities.

Measuring performance for construction projects is a complex problem, and it is the heart of ceaseless improvement (Luu et al., 2008). Every project is unique in terms of design specifications, delivery methods, administration, and participants. Therefore, evaluation of performance has been a challenge for the construction industry for several decades (Khanh, 2011). However, such wastes has not been identified clearly by project managers. No accurate method has been developed to quantify incidence of waste in construction industry. Forsberg and Saukkoriipi (2007) stated that two principally different ways of minimizing the production cost is to either increase productivity or to reduce waste. In addition, no practical and acceptable means has been agreed by all parties involved in construction projects in reducing the wastes significantly.

In the past, professionals in the construction industry have considered that the wastes were directly associated with only the debris removed from the site activities (Formoso et al., 2002). Most of wastes were related to the gaps in management and operation system because of less care in eliminating wastes. Furthermore, each project has a different level of waste for same source of materials; therefore, a significant number of waste exist in the construction processes and many of them are not known or hidden (Formoso et al., 2002).

Pheng and Tan (1998) defined waste in construction as the different between the value of materials delivered and accepted on site and materials used properly as specified and accurately measured in the work. Many previous studies have also shown that wastes in construction are related to materials. Skoyles (1976) claimed that the amount of waste measured in UK construction industry varied from 2% to 15% in relation to amount of materials defined by design. Bossink and Brouwers (1996) indicated that 9% of total purchased materials end up as waste and 1-10% of every purchased construction material leaves the site as solid waste in the Dutch construction industry. Similarly, it is 20-30% for Brazilian construction industry. Since materials account for 50-60% of a construction project cost, any improvement avoiding material waste results in major cost savings (Wong and Norman, 1997)

Nowadays, under the new production philosophies, wastes are understood as inefficiency in using equipment, materials and manpower for the production activities or using amount of capital larger than needed (Tan, 2004). Since then, the wastes are considered as any material damages related to cost and productivity by not adding a value to final output production. Koskela (1993) defined that *"the value-adding activity is an activity that* *converts material and/or information towards that which is required by the customer, and the non value-adding activity is an activity that takes time, resources or space but does not add value"*. Furthermore, Formoso et al. (1999) also defined that *"non value-adding activity is any loss produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client"*. Therefore, the lean philosophies have separated production activities into value adding activities and non value-adding activities. An example in construction practice for this separation can be found in Christian et al. (1995). They indicated that workers spend only approximately 46% of working time for the value-adding activities, and 54% for non value-adding activities from seven sites. Furthermore, Ciampa (1991) claimed even worse results that only 3 to 20% of steps add value, and their share of the total cycle time is negligible from 0.5 to 5%. Thus, reduction of non value-adding activities offers a major development potential in most performance processes.

The new production philosophies consider non value-adding activities as wastes, and also propose several principles to reduce or eliminate them in the conventional viewpoint especially in creating an opportunity cost. In detail, the conventional viewpoint considered the total project cost as the cost of all activities; whereas the new philosophy viewpoint considered it as cost of non value-adding activities and cost of value-adding activities (Koskela, 1992). Since then, performance improvement strategies could be done better by reducing or eliminating the non value-adding activities, and total cost of project could be reduced because process efficiency increased.

In this new waste model, production should be seen as a flow that generates value through conversion processes characterized by cost, time frame and degree of added value. In other words, the new production theory seeks cycle time reduction, total waste elimination, no defects and flexible output. In construction, the application of the lean production model mainly stems from a discussion of Koskela's model (1992) which has proposed a flow process conceived from materials and information through four types of stage: (1) transport (or moving), (2) waiting (or delay), (3) processing (or conversion), and (4) inspection. Furthermore, based on Shingo's seven wastes (1988) in Toyota manufacturing system, Formoso et al. (1999) have proposed the main classification of wastes based on the analysis of some Brazilian building sites as follows: (1) overproduction, (2) substitution, (3) waiting time, (4) transportation, (5) processing, (6) inventories, (7) movement, (8) production of defective products, and (9) others. Based on the ratio of prevention investment cost over the cost of waste itself, they have classified wastes into two general groups: (i) unavoidable wastes and (ii) avoidable wastes. Although waste is usually identified during production phase, it can be originated by processes that precede production system such as material manufacturing, training of human resources, design, material supply, and planning. Thus, wastes can be seen by dividing total process into orderly smaller processes (Tan, 2004).

The classification of wastes was mainly based on the philosophies of LC involving three groups (nineteen factors) as shown in Table 3.2 (Koskela, 1993; Serpell et al., 1995; Alarcon, 1994 & 1995, and Formoso et al., 1999 & 2002). They are: (I) direct conversion wastes that pertain to manpower, materials, and equipment when performing an activity; (II) non-contributory time wastes that pertain to time for waiting, idling, and travelling; and (III) contributory time wastes that pertain to time for supervision, inspection, transport, instruction, and communication.

Table 3.2 Construction waste factors

#		Waste factor	(1)	(2)	(3)	(4)	(5)
I		**Direct conversion waste**					
	Q1	Over-allocated/ unnecessary equipment on site	O	O		O	
	Q2	Over-allocated/ unnecessary materials on site	O	O		O	
	Q3	Over-allocated/ unnecessary workers on site	O	O		O	O
	Q4	Unnecessary procedures and working protocols	O				
	Q5	Material lost/ stolen from site during construction period			O		O
	Q6	Material deteriorated/ damaged during construction period		O			O
	Q7	Mishandling or error in construction application/ installations		O	O		O
	Q8	Materials for reworks/ repaired works/ defective works	O	O	O	O	O
	Q9	Accidents on site			O		O
II		**Non-contributory time waste**					
	Q10	Waiting for others to complete their works before the proceeding works can be carried out	O		O	O	
	Q11	Waiting for equipment to be delivered on site	O	O	O	O	O
	Q12	Waiting for materials to be delivered on site	O	O	O	O	O
	Q13	Waiting for skilled workers to be provided on site	O		O	O	O
	Q14	Waiting for the clarification and confirmation by client and consultants	O	O	O	O	
	Q15	Time for reworks/ repaired works/ defective works	O	O	O	O	O
	Q16	Time for workers' rest during construction	O			O	
III		**Contributory time waste**					
	Q17	Time for supervising and inspecting the construction works	O			O	
	Q18	Time for instructions and communication between engineers and workers	O			O	O
	Q19	Time for transporting workers, equipment and materials	O		O	O	

Note: (1) – Serpell et al. 1995; (2) – Alarcon 1994 & 1995; (3) – Formoso et al. 1999 & 2002; (4) – Koskela 1993, and (5) – Alwi et al. 2002.

In addition, Alarcon (1994 & 1995) listed fifteen potential causes of waste related to administration, use of resources, and information system. On the other hand, Serpell et al. (1995) also determined three main causes of waste associated with activities of flow, conversion and management. Therefore, the causes of waste can be classified into five groups (twenty-three factors) as shown in Table 3.3. They are: (A) management/ administration cause; (B) people cause; (C) execution/ performance cause; (D) material/ equipment cause; and (E) information/ communication cause.

Table 3.3 Causes of construction wastes

#	Cause factor	(1)	(2)	(3)
A	**Management/ administration cause**			
	A1. Poor coordination among project participants			O
	A2. Poor planning and scheduling	O	O	O
	A3. Lack of control	O	O	
	A4. Bureaucracy		O	
B	**People cause**			
	B1. Lack of trade skills			O
	B2. Inexperience inspectors		O	O
	B3. Too few supervisors/ foreman	O		O
	B4. Too late supervision	O		O
	B5. Poor worker/ equipment distribution	O	O	O
C	**Execution/ performance cause**			
	C1. Inappropriate construction methods			O
	C2. Outdated equipment	O		O
	C3. Equipment shortage	O	O	O
	C4. Poor equipment choice or ineffective equipment	O		O
	C5. Poor site layout		O	O
	C6. Poor site documentation		O	O
D	**Material cause**			
	D1. Poor material delivery schedule			O
	D2. Poor quality of materials		O	O
	D3. Inappropriate materials/ misuse of materials		O	O
	D4. Poor storage of materials		O	O
	D5. Poor material handling on site		O	O
E	**Information/ communication cause**			
	E1. Defective or wrong information	O	O	
	E2. Late information and decision making	O	O	
	E3. Unclear information	O	O	

Note: (1) – Serpell et al. 1995; (2) – Alarcon 1994 & 1995; and (3) – Alwi et al. 2002.

3.4 Summary

This chapter has introduced the concepts of wastes in lean production, as well as its causes. Based on the literature review, there are a total of nineteen waste factors and twenty-three waste causes found in this study. In general, waste causes a considerable value loss for construction project.

CHAPTER 4

RESEARCH METHODOLOGY

4.1 Introduction

This chapter will explain the methodology used to carry out this research. From the literature review of previous works, the principles and tools of lean production could be applied in the construction industry to improve the current efficiency. The main purpose of this study is to examine the waste problems in construction projects in Vietnam. The new concept of waste is not only related to materials, but also related to time. The following sections comprehensively describe the systematic methods to accomplish the objectives of this study, i.e., conceptual research framework, survey population, questionnaire survey, expert survey, analysis tools, overall analysis process, and summary.

4.2 Conceptual research framework

Prior to considering the full potential of LC's principles and tools in reducing and controlling the wastes, the current practice of the construction industry should be investigated first. In order to gain the research purposes as mentioned in the previous chapter, a conceptual framework is drawn in step-by-step as shown in Figure 4.1.

4.3 Survey population

A randomly selected group of targeted respondents consists of personnel who have a commanding role in the construction process and resource management, and extensive site experiences were targeted as respondents for the sample survey. There is a wide spectrum of personnel with different position and job title. The whole sample of respondents can be regrouped into two main categories as follows:

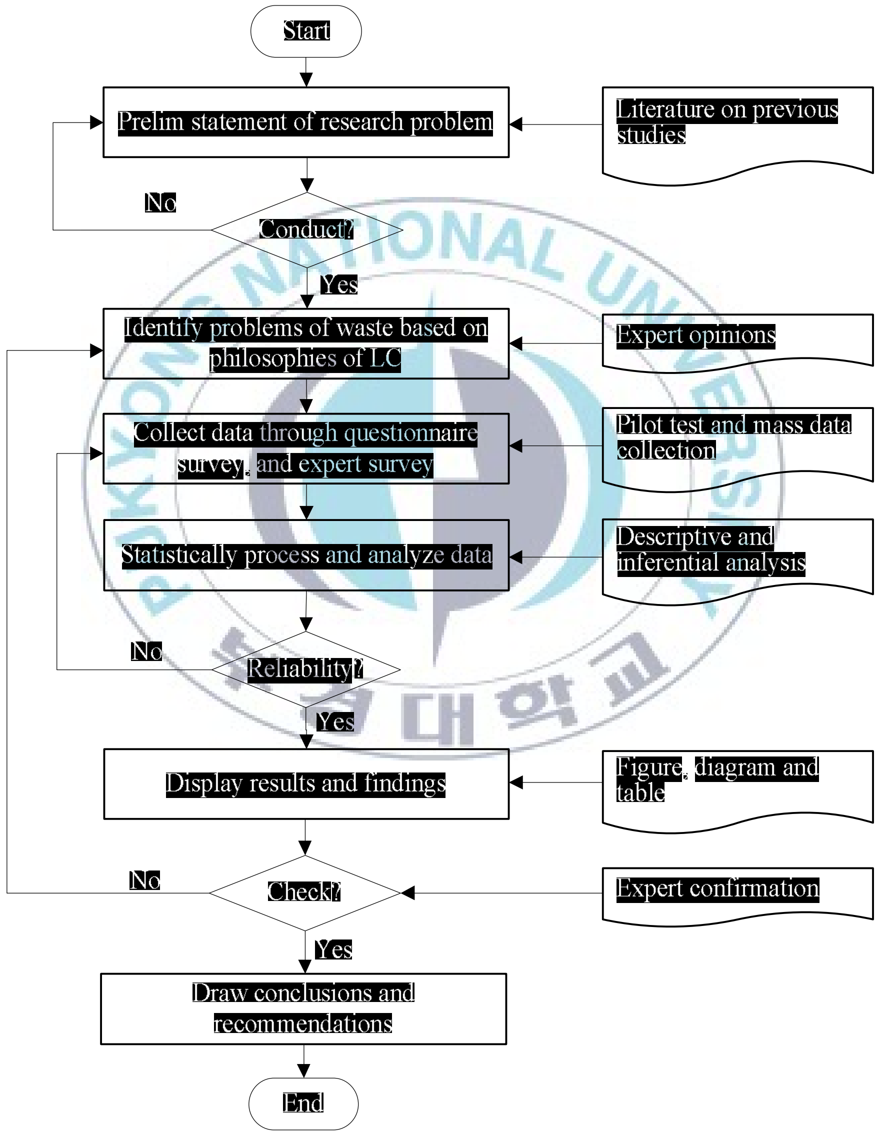


Figure 4.1. Conceptual framework for research problems

1. Project management orientated group: This group will feature those who have relatively more responsibilities in overall project execution and resource management and not so much on site operative management by its nature of job scope. Therefore, it will involve personnel in planning, inter-coordinating and directing role in construction process, and as for the sample respondents for this research will include project managers, general managers, project planners, etc.
2. Site operative management orientated group: This group will feature those who have relatively more responsibilities on the site operative management by its nature of job scope. The group will mainly involve personnel in solving construction problems on site, more on intra-coordinating with internal groups and trades, and as for the sample respondents for this research will include site managers, department leader (QS, QA and QC), site engineers, and foremen.

4.4 Questionnaire survey

Due to the unavailability of documented data of completed projects for research in Vietnam, a questionnaire survey has been decided to be employed. The role of questionnaire is to provide a standardized interview across all subjects. All respondents are asked the questions that are appropriate to them, and so that, when those questions are asked, they are always asked in the same way (Brace, 2004). The difficulty of this study is the far distance between the researcher and the targeted respondents. Therefore, the questionnaire has been considered as the most sufficient way of remote communication between them. The following principles are maintained during survey design and implementation:

- Pick up enough sample size considering the common response rate;
- Phrase and organize the questions in a clear and logical way;
- Avoid offensive or sensitive questions;
- Maintain the length of questions so that the respondent could finish them within a short time period (less than 20 minutes);
- Conduct pilot test the questionnaire by few respondents;
- Send the appropriate reminder to non-respondents.

The questionnaire survey can be basically divided into three steps: (1) Questionnaire design, (2) Questionnaire distribution, and (3) Data collection and preliminary analysis. The process for survey is described in Figure 4.2.

4.4.1 Questionnaire design

In this step, pilot test with experts group will be conducted to test the suitability of the questionnaire. Before conducting the pilot test, potential items were extracted from literature review and practitioners in professional forum. These works help to form a preliminary questionnaire.

It is decided to test this draft version of the questionnaire with experts. A group of five experts were invited to participate the pilot test. All these experts are practitioners in the VCI. They have much experience in construction engineering and management with at least ten years involved in construction field. The experts are asked to review the sufficiency and appropriateness of the problems and the structure of the questionnaire. Two rounds of pilot test are needed to finish the pilot test. After that, all items which are considered as potential problems for research objectives are finalized in the official questionnaire.

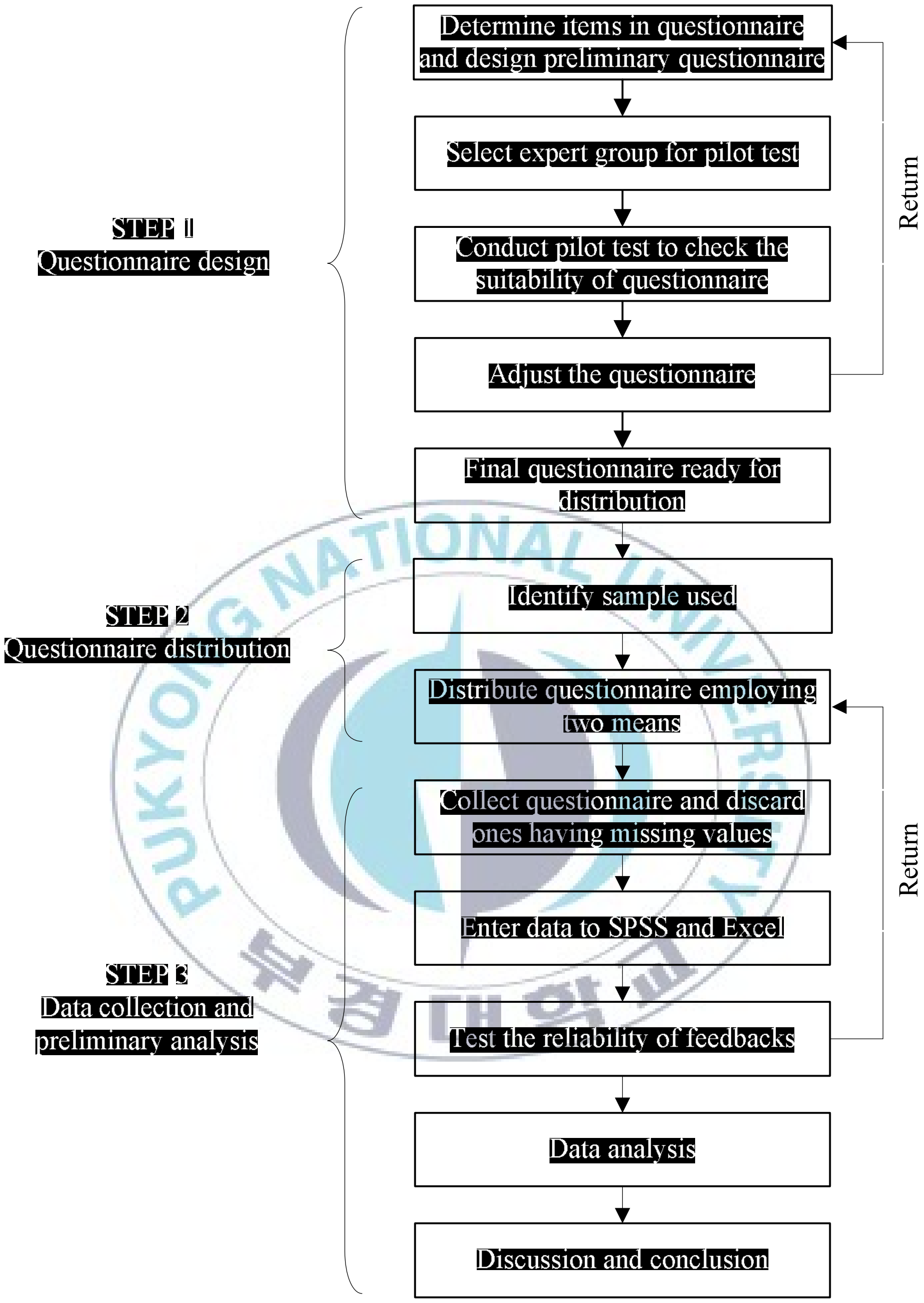


Figure 4.2. Flowchart of questionnaire survey process

The contents of the questionnaire (see Appendix 1) for collecting data from respondents according to six research objectives as follows:

1) Waste recognition and control: The respondents are asked to recognize waste factors and assess the ability of controlling these wastes during construction processes. The “yes/no” question is employed in this section.

2) Waste occurrence and its impact: The respondents are asked to rate their agreement to frequency of waste occurrence in construction projects according to five-point Likert scale from 1 for “Never” to 5 for “Very frequently”. They are then asked to evaluate the effect of wastes on project performance cost based on their experience. A type of self-filled question in terms of percentage is adopted in this situation.

3) Identification of possible waste causes: The respondents are asked to rate the likelihood of particular waste causes in construction projects according to four-point Likert scale from 1 for “Most unlikely” to 4 for “Most likely”.

4) Cause-and-effect relationship between wastes and its causes: The respondents are asked to identify the main causes for each waste element in order to create a relationship matrix.

5) Personal information: Some questions related to personal information of respondents are asked in this section.

4.4.2 Questionnaire distribution

The purposes of this research are to see whether or not the lean construction principles related to waste have been well comprehended, accepted and adopted by the local construction personnel for the continuous improvement in construction processes. A quantitative research approach is adopted for this research requiring the development and dissemination of a questionnaire survey. Due to the population of this research are virtually very difficult to be quantified as the main targeted respondents would include all personnel who has direct managerial experiences in construction field, the non-probability sampling methods will be adopted in this research instead of probability sampling.

In Vietnam, there is no organization recording or managing the construction practitioners profiles. Therefore, the researcher employs a self-administered questionnaire distribution. The involved practitioners in the survey are identified through construction companies' websites and charters, professional forum, project case analyses, and researcher's personal relationship. It is noted that the brief information about the definition of waste is described at the beginning section of the questionnaire. Two main methods for delivering the questionnaire are adopted in this study including electronic mailing and internet survey link. The area of sampling is in Ho Chi Minh city, Vietnam. The first duration for collecting mass data is one month. After one month, a remind contact is conducted to people who do not reply the questionnaire. All responses after this due day will be discarded.

4.4.3 Preliminary analysis

The main purpose of this step is to collect and filter the feedbacks from the respondents. All the raw collected data will be put in a prepared sheet of Microsoft Excel for preliminary treatment. Questionnaires which are not fully answered by respondents will be discarded in this step. The data will be then classified into qualitative data and quantitative data. Moreover, they are also classified into data that need to be solved by inferential statistical tools or descriptive statistical tools.

Before processing data, the reliability of the respondents' feedbacks should be checked first. In this case, the Cronbach's alpha coefficient of internal consistency value, which is consider to be reliable if the value is greater than 0.7, is used to test scale score. The appropriate responses are then entered into the statistical software, namely Statistical Package for the Social Science (SPSS, version 18.0). This activity makes out the data set for this study. The detailed analysis results and discussion are presented in the following chapter.

4.5 Expert survey

The main purpose of experts survey is to request for their help with the accuracy of the research problems. In detail, before conducting to collect mass data, referring the opinions of experts to certify the feasibility of the research problems are needed. Furthermore, the confirmation of experts to the results of analysis is also required in this study. These actions make the study more reliable and practical. Because of the far distance between the researcher and experts, a check sheet of research findings is adopted in this situation. The experts are requested to answer the 'yes/no" questions for each finding. They can also fill their comments at the end of the check sheet that they think these comments are helpful to the research findings.

4.6 Analysis tools

In this section, the statistical tools and techniques employed in the study will be briefly presented. Essentially, there are two kinds of statistical analysis include descriptive statistical analysis and inferential statistical analysis.

4.6.1 Descriptive analysis

Min and max

- *Min value (minimum)* is the smallest value of a data set. In this study, min value is the smallest value of the respondents' rating for each item in the questionnaire.
- *Max value (maximum)* is the largest value of a data set. In this study, min value is the largest value of the respondents' rating for each item in the questionnaire.

Mean

Mean (often represented by the Greek symbol μ, or the letter $\overline{X}$) is a measure of central tendency either of a probability or of the random variable characterized by that distribution. For a finite population, the population mean of a property is equal to the arithmetic mean of the given property while considering every member of the population. This parameter is used very frequently in descriptive statistical field. In this study, the mean value of one item is calculated by adding all respondents' ratings and then dividing by the number of the respondents for this item. The formula for calculating the mean is described as follows:

$$\mu = \frac{\sum_{i=1}^{n} X_i}{n} \tag{3.1}$$

Where:

- X_i: rating of respondent i;
- n: sample size;
- μ: the mean of the data sample;

Standard deviation

Standard deviation (represented by the symbol sigma σ, and often abbreviated by SD) shows how much variation or dispersion exists from the mean, or expected value. A low standard deviation indicates that the data points tend to be very close to the mean, whereas high standard deviation indicates that the data points are spread out over a large range of values. In addition to expressing the variability of a population, standard deviation is commonly used to measure the confidence in statistical conclusions. The standard deviation is the square root of its variance. The formula for calculating the standard deviation is expressed as follows:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}\left(X_i - \bar{X}\right)^2}{n}} \qquad (3.2)$$

Where:

- X_i: rating of respondent i;
- $\bar{X}$: the mean of the data sample;
- n: sample size;
- σ: standard deviation.

4.6.2 T-test

A *t*-test is a statistical examination of the mean of two sets of data. A two-sample *t*-test examines whether two samples are significantly different from each other. It is commonly used when the variances of two normal distributions are unknown and when an experiment uses a small sample size. The test statistic in the *t*-test is known as the *t*-statistic. The *t*-test looks at the *t*-statistic, *t*-distribution and degrees of freedom to determine a *p*-value (probability) that can used to determine whether the means differ. The t-test is one of many hypothesis tests.

In this study, the *t*-test is employed to explore the difference between the means of predicted values and actual values of project cost increased due to wastes. Therefore, the hypothesis can be stated as follows:

- Null hypothesis (H_0): There is no significant difference between the mean of predicted values (μ_p) and the mean of actual values (μ_a).

$$\mu_p - \mu_a = 0$$

- Alternative hypothesis (H_A): There is a significant difference between the mean of predicted values (μ_p) and the mean of actual values (μ_a).

$$\mu_p - \mu_a \neq 0$$

Before performing a two-sample *t*-test, the assumptions and conditions should be checked first. They are "independent assumption", "randomization condition", and "10% condition". The p-value is then defined based on the t-value to make conclusion about the acceptance or rejection of the null hypothesis. The following formulas are used to determine t-value (De Veaux et al., 2009):

$$SE = \sqrt{\frac{\sigma_p^2}{n_p^2} + \frac{\sigma_a^2}{n_a^2}} \tag{3.3}$$

$$t = \frac{\mu_p - \mu_a}{SE} \tag{3.4}$$

$$df = (n_p - 1) + (n_a - 1) \tag{3.5}$$

Where:

- SE: standard error;
- σ_p, σ_a : standard deviation of predicted values and actual values, respectively;
- n_p, n_a: sample size of predicted values and actual values, respectively;
- μ_p, μ_a: mean of predicted values and actual values, respectively;
- t: the statistic of two samples;
- df: degree of freedom.

4.6.3 Ranking

A ranking is a relationship between a set of items such that, for any two items, the first is either 'ranked higher than', 'rank lower than' or 'ranked equal to' the second. It is not necessarily a total order of objects because two different objects can have the same ranking. The rankings themselves are totally ordered.

In this study, mean value method is employed to analyzed the data in the beginning. The rating of respondents according to five point scale is used to compute mean score for each item. Items in each group are ranked based on their computed score. The rule of making ranking is "item having higher mean score is ranked higher than item having lower mean score".

4.6.4 Crosstabs

A crosstab is a statistical process that summarizes categorical data to create a contingency table. Commonly, crosstabs are concatenations of multiple different tables. They provide a basic picture of the interrelation between two variables and can help find interactions between them. In this study, a kind of crosstab is used to show the relationship between the recognition ability and control ability of waste factors. Therefore, there are four different scenarios anticipated as below:

Scenario 1. Waste factors are recognized as waste, and they have been paid a proper attention in controlling them;

Scenario 2. Waste factors are not recognized, but they are controlled;

Scenario 3. Waste factors are recognized as waste, but they are not controlled, and

Scenario 4. Waste factors are not recognized as waste, and they have not been given any control actions into it;

The explanation for each scenario can be described as the Table 4.1 below:

Table 4.1 Four scenarios of waste recognition and control ability

	Controlled	Not controlled	*(Marginal probability)*
Recognized	Scenarios 1	Scenarios 3	
Not recognized	Scenarios 2	Scenarios 4	
(Marginal probability)			(1.000)

4.6.5 Pearson correlation test

The Pearson's correlation coefficient is a measure of the strength of the linear correlation (or dependence) between two variables. It is defined as the covariance of the two variables divided by the product of their standard deviations. When applied to a population or a sample, it is commonly represented by the Greek letter ρ (rho) or letter r_p, respectively. In this study, Pearson-r analysis is used to demonstrate that whether there is a significant correlation between each pair of recognition, control and frequency of waste, and between waste occurrence and production planning. The formula for r_p is as follows:

$$r_p = \frac{\sum_{i=1}^{n}(X_i - \mu_X)(Y_i - \mu_Y)}{\sqrt{\sum_{i=1}^{n}(X_i - \mu_X)^2}\sqrt{\sum_{i=1}^{n}(Y_i - \mu_Y)^2}} \tag{3.6}$$

Where:

- X_i, Y_i: two variables considered;
- μ_X, μ_Y: standard deviation of two samples;
- n: sample size;
- r_p: Pearson correlation coefficient.

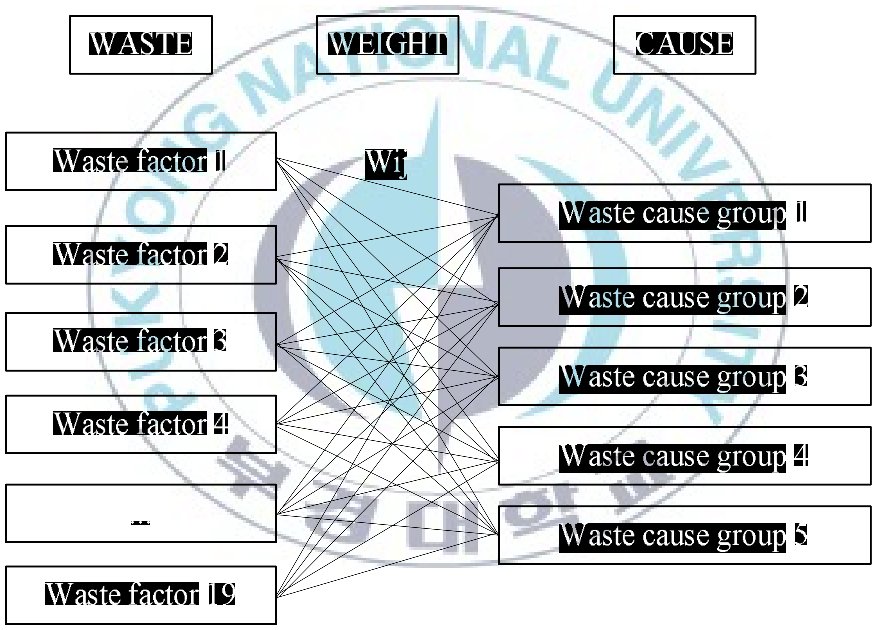
Null hypothesis that the variables based on respondent's rating are correlated will be rejected at the significance level of 0.05 with two-tail probability distribution. The null hypothesis can be stated as follows:

- Null hypothesis (H_0): There is no significant relationship between variables ($r_p = 0$)
- Alternative hypothesis (H_A): There is a significant relationship between variables ($r_p \neq 0$)

The Pearson's correlation coefficient is analyzed to see the magnitude and direction of the association between two variables. In SPSS, the outcomes of the Pearson analysis include three pieces of information: (1) the correlation coefficient, (2) the significance level, and (3) the number of cases.

The correlation coefficient is a number between +1 and -1. The closer the correlation is to either +1 or -1, the stronger the correlation is. If the correlation is 0 or very close to zero, there is no association between the two variables. The direction of the correlation shows how the two variables are related. If the correlation is positive, the two variables have a positive relationship, and vice versa, if the correlation is negative, the two variables have a negative relationship.

4.6.6 Cause-and-effect analysis



Note: i is from 1 to 19 according to 19 waste factors, and j is from 1 to 5 according to 5 waste cause groups

Figure 4.3 Model of cause-and-effect relationship

Causality is the relation between an event (the cause) and a second event (the effect), where the second event is understood as a consequence of the first. In common usage, causality is also the relation between a set of factors (cause) and a phenomenon (the effect). Anything that generates an effect is a factor of that effect. A direct factor is a factor that generates an effect directly, that is, without any intervening factors. The connection between a cause(s) and an effect in this way can also be referred as a causal nexus, or a cause-and-effect relationship.

In this study, cause-and-effect analysis is employed to understand the relationship between nineteen waste factors and their twenty-three causes. The model of cause-and-effect relationship is illustrated in Figure 4.3. The main cause for each waste factor is then identified based on the maximum weight (w_{ij}) from respondents' answer. For instance, if the causes for waste factor 1 has their weight as: 10% cause 1, 20% for cause 2, 50% for cause 3, 10% for cause 4, and 10% for cause 5, the main cause is defined as cause 3. It is similar to other waste factors.

4.6.7 Factor analysis

In this study, there may be latent relationships between waste factors. To explore the underlying relationships, factor analysis method is applied. Factor analysis is a statistical method used to describe variability among observed variables in terms of a potentially lower number of unobserved variables called factors. Therefore, the major purpose of factor analysis is the orderly simplification of a large number of inter-correlated measures to a few representative factors. Factor analysis is based on the assumption that all variables are correlated to some degree. Those variables that share similar underlying dimensions should be highly correlated, and those variables that measure dissimilar dimensions should yield low correlations (Robert, 2006).

There are three basic steps to conduct factor analysis:

1. Testing the applicability of factor analysis;
2. Extraction of initial factors;
3. Rotation of the extracted factors to a terminal solution.

The communality for a given variable can be interpreted as the proportion of variation in that variable explained by the extracted factors. The communalities of all problems included in factor model must be greater than 0.5 as rule of thumb to signify the reliability of the model. Factor analysis searches for such joint variations in response to unobserved latent variables. The observed variables are modeled as linear combinations of the potential factors, plus "error" terms. The information gained about the interdependencies between observed variables can be used later to reduce the set of variables in a dataset.

As factor analysis is based on correlations between measured variables, a correlation matrix containing the inter-correlation coefficients for the variables should be inspected. There is a need of sufficient significant correlation in data matrix to justify the application of factor analysis. Bartlett's test of sphericity which indicates whether the correlation matrix is not an identity matrix must be significant at 0.05. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy should be over 0.7 (Sharma, 1996). According to latent root criterion, all extracted components must have eigenvalues larger than 1.0. As a rule of thumb, factor loadings less than 0.5 are suppressed and only problems with loading having larger than 0.5 are shown in the factor analysis result. The Varimax rotation method is employed in this study. Figure 4.4 shows the process of factor analysis performance in step-by-step.

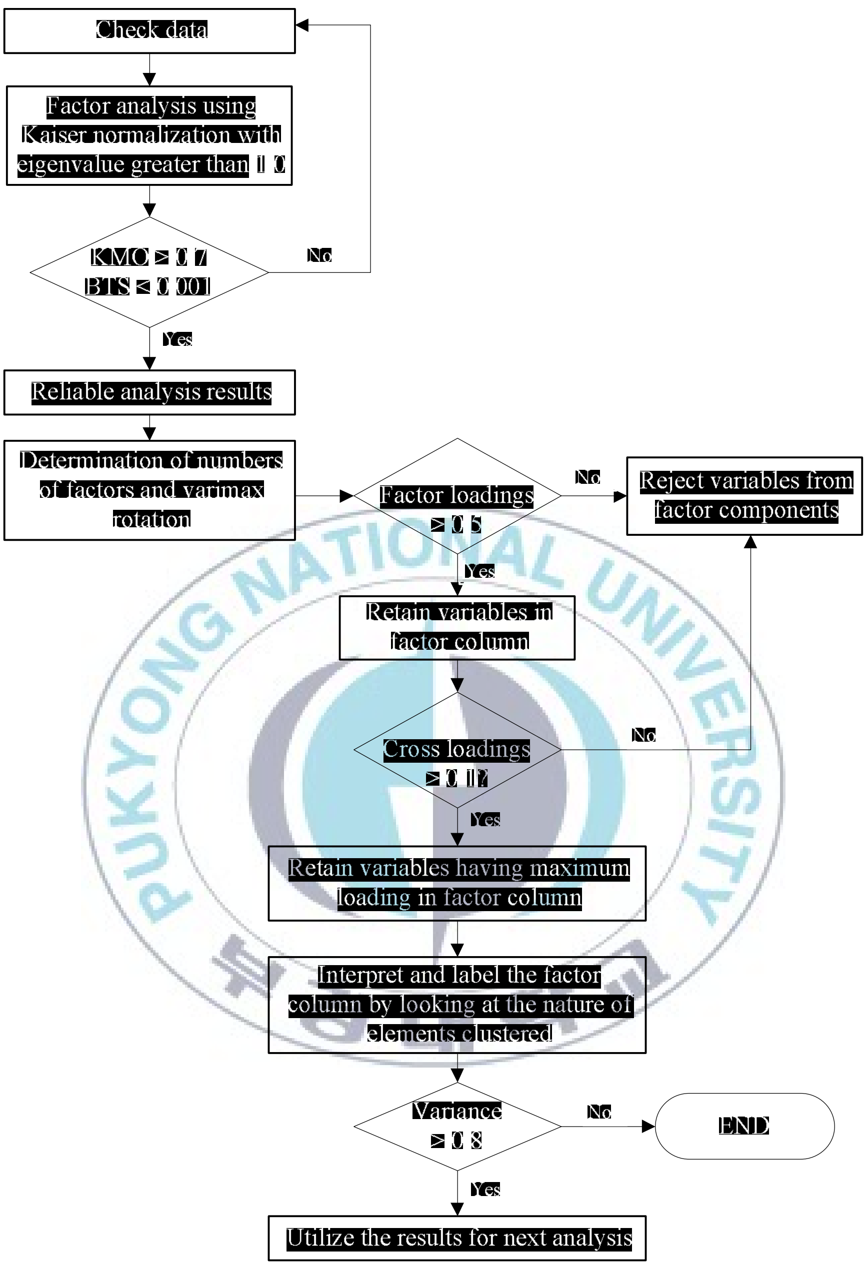


Figure 4.4 Process of factor analysis performance

4.6.8 Linear regression

In statistics, Linear Regression (LR) is an approach to model the relationship between a scalar dependent variable y and one or more explanatory variables denoted X. The case of one explanatory variable is called simple linear regression. For more than one explanatory variable, it is called the multiple linear regression.

In linear regression, data are modeled using linear predictor functions, and unknown model parameters are estimated from the data. Such models are called linear models. Most commonly, linear regression refers to a model in which the conditional mean of Y given the value of X is an affine function of X. Less commonly, linear regression could refer to a model in which the median, or some other quartile of the conditional distribution of y given X is expressed as a linear function of X. Like all forms of regression analysis, linear regression focuses on the conditional probability distribution of Y given X, rather than on the joint probability distribution of Y and X, which is the domain of multivariate analysis.

Linear regression was the first type of regression analysis to be studied rigorously, and to be used extensively in practical applications. This is because models which depend linearly on their unknown parameters are easier to fit than models which are non-linearly related to their parameters and because the statistical properties of the resulting estimators are easier to determine.

Given a data set $\{Y_i, X_{i1},..., X_{ip}\}_{i=1}^{n}$ of n statistical units, a linear regression model assumes that the relationship between the dependent variable Y_i and the p-vector of independent variable X_i is linear. This relationship is modeled through a disturbance term or error variable ε_i – an unobserved random variable that adds noise to the linear relationship between the dependent variable and independent variables. Thus, the model takes the form:

$$Y_i = \beta_1 X_{i1} + ... + \beta_p X_{ip} + \varepsilon_i \qquad (i = 1,2,...,n) \qquad (3.7)$$

4.6.9 Artificial neural network

An Artificial Neural Network (ANN) is a mathematical model inspired by biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases, a neural network is an adaptive system changing its structure during a learning phase. Neural networks are used for modeling complex relationships between inputs and outputs. An ANN is typically defined by three types of parameters:

1. The interconnection pattern between different layers of neurons;
2. The learning process for updating the weights of the interconnections;
3. The activation function that converts a neuron's weighted input to its output activation.

ANN types vary from those with only one or two layers of single direction logic to complicated directional feedback loops and layers. On the whole, these systems use algorithms in their programming to determine control and organization of their functions. There are three major learning paradigms, each corresponding to a particular abstract learning task. These are supervised learning, unsupervised learning, and reinforcement learning. An ANN model is employed according to three steps as follows:

1. Choice of model: This depends on the data representation and the application. Overly complex models tend to lead to problems with learning;

2. Learning algorithm: There are numerous trade-offs between learning algorithms. Almost any algorithm will work well with the correct hyper-parameters for training on a particular fixed data set. However, selecting and tuning an algorithm for training on unseen data requires a significant amount of experimentation;
3. Robustness: If the model, activated function and learning algorithm are selected appropriately, the resulting ANN can be extremely robust.

In this study, ANN is used to develop a model to predict the effect of waste factors on project performance cost. The Percentage Error (PE), Mean Absolute Percentage Errors (MAPE) and R^2 indices are adopted to measure the accuracy of the model as follows:

$$PE = \frac{Predicted\ \text{-}\ Actual}{Actual} \times 100\% \qquad (3.8)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \frac{|Predicted\ \text{-}\ Actual|}{Actual} \times 100\% \qquad (3.9)$$

$$R^2 = 1 - \frac{Sum\ of\ squared\ errors}{Total\ sum\ of\ squares} \qquad (3.10)$$

4.6.10 Elasticity test

The possible impact of the input variables on the targeted variable may be determined via an elasticity test (Venkataraman et al., 1995). This is done by perturbing each of the input variables in the output due to the change in the independent variables is taken to reflect the influence of the variable on the output.

The input variables are waste factors, and the output variable is the project performance cost loss due to wastes. The elasticity of the cost with respect to the *k*-th waste factor, E_k, is expressed as follows:

$$E_k = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\Delta P}{\Delta W_k}\right)_i \times 100\% \qquad (3.11)$$

Where:

- ΔP: the change in increased project cost due to a corresponding reflection with change (ΔW_k) in the *k*-th input variable;
- i: a subscript denoting the ratio obtained for the *i*-th data set;
- n: the number of data sets considered;
- E_k: the elasticity of the project cost for the *k*-th input variable.

In this study, the values for each input variable are defined based on five-point Likert scale. Therefore, it is recommended that the process of performing elasticity test in this study is done by adding 1 to each value of all data sets collected as a loop from 1 to 5. It means that ΔW = 1 for each time of data run in the total of five run times. The change in the output (ΔP) will be then identified in corresponding with each ΔW. The elasticity (E) for each case is defined based on the difference between the new and old mean value of output.

The model used to perform the elasticity test is either artificial neural network (ANN) model or linear regression model. Figure 4.5 shows the process of elasticity test performance in step-by-step.

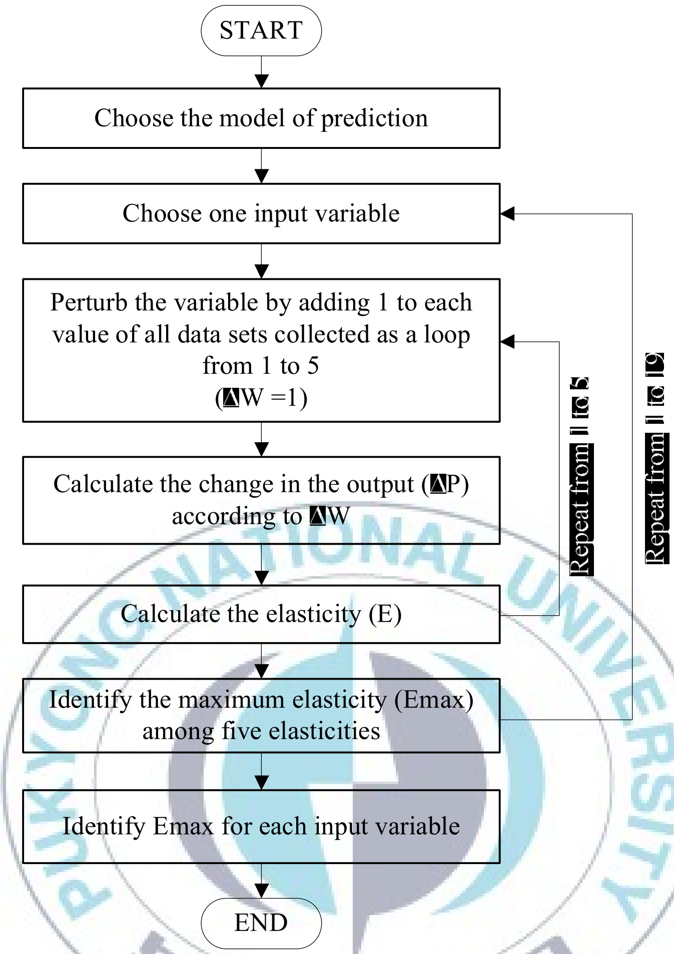


Figure 4.5 Process of elasticity test performance

4.7 Summary

This chapter has introduced the methods for conducting this study. It included conceptual framework for research problems, questionnaire design, expert survey, and analysis tools. The overall process of data analysis according to research's objectives is illustrated as Figure 4.6.

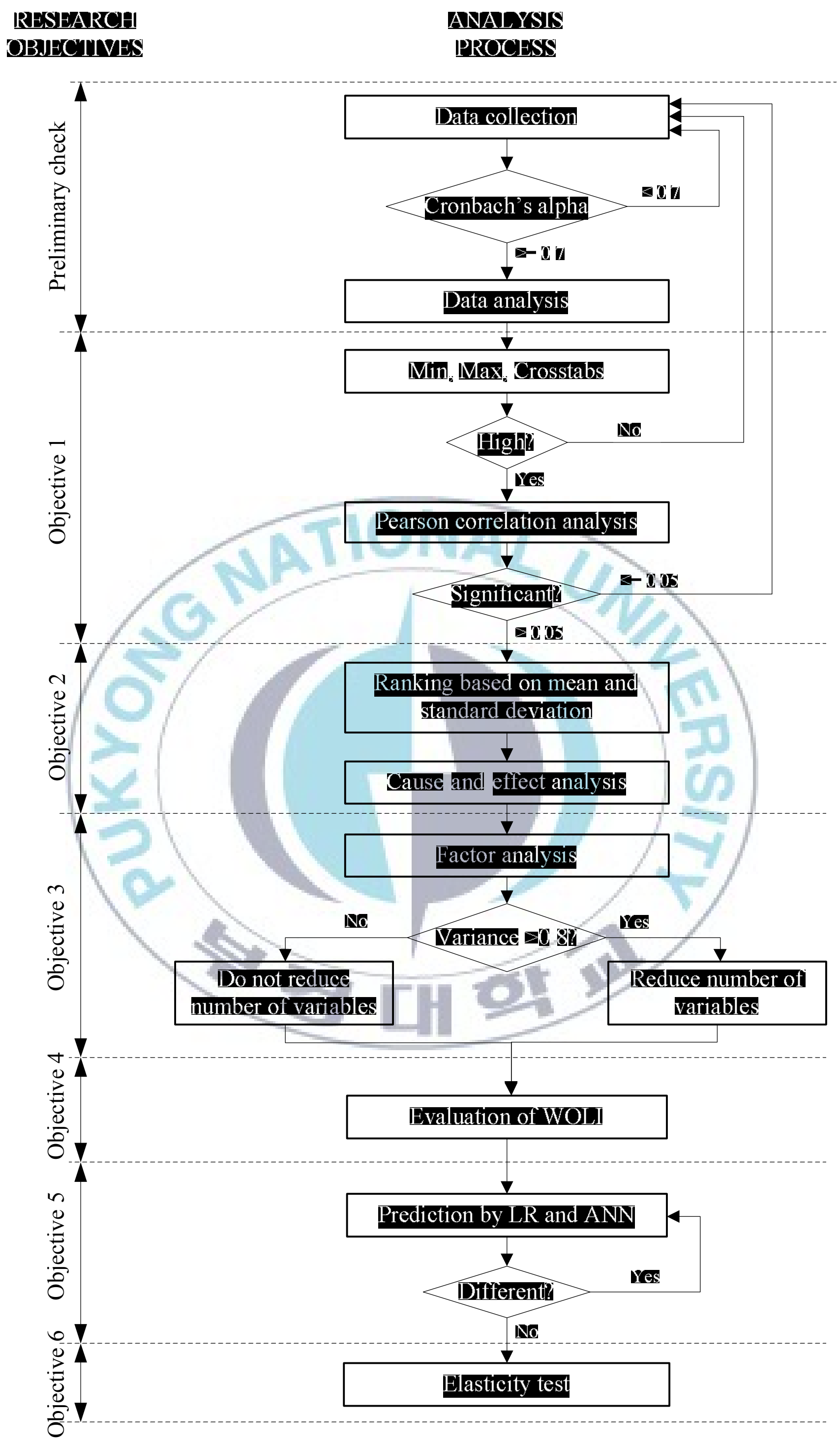


Figure 4.6 Overall process of data analysis according to research's objectives

CHAPTER 5

ANALYSIS RESULTS

5.1 Introduction

The findings of questionnaire survey are reported in this chapter. It includes following sections: brief description of data collection, data analysis results, comparison with selected countries, discussion, and summary. Figure 5.1 shows the process of research in this chapter.

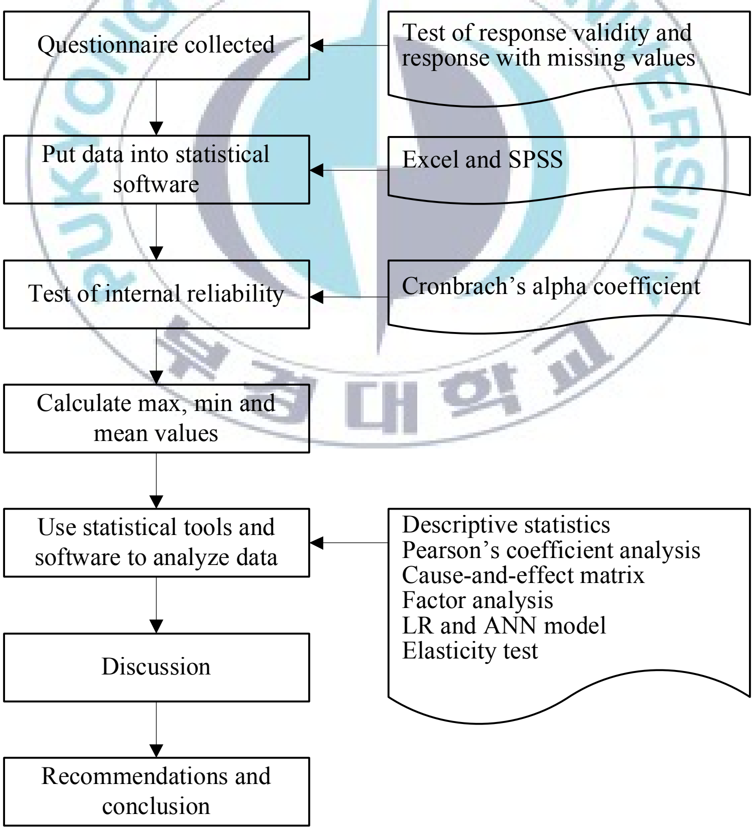


Figure 5.1 Flowchart of chapter's research process

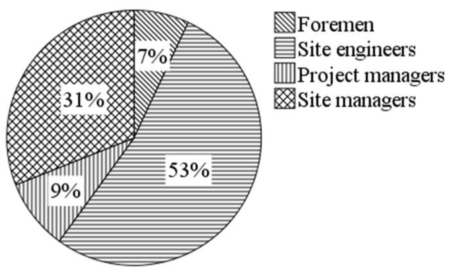
5.2 Data collection

A questionnaire (in Vietnamese) consisting of nineteen waste factors Table 3.2 and twenty-three waste causes mentioned in Table 3.3 was designed. A total of 297 copies of the questionnaire have been distributed to the personnel in Ho Chi Minh city, Vietnam. Responses were received from 159 professionals. After filtering these, only 128 numbers of responses were found to be usable. Thus, rate of response in this study is 43%.

Cronbach's alpha coefficients of internal consistency reliability test for frequency of responses for waste factors and causes of waste are 0.860 and 0.812, respectively (Table 5.1). According to the commonly accepted rule of thumb, internal consistency is good when Cronbach's alpha coefficient is between 0.8 and 0.9. Therefore, the collected data are validity for carrying out the prospective analysis.

Table 5.1 Cronbach's alpha coefficients

Frequency of response	Cronbach's alpha	Sample size
Waste factors	0.860	128
Causes of waste	0.812	128



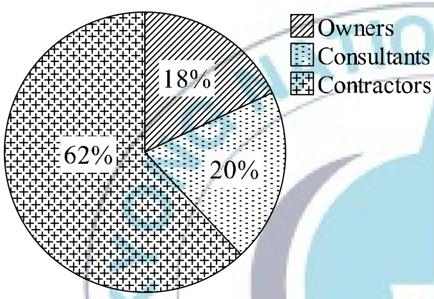
Position	Frequency	Percent
Foreman	4	3.0
Site engineer	84	66.0
Project manager	33	26.0
Site manager	7	5.0

Figure 5.2 Position of respondents in project

5.3 Data analysis

5.3.1 Respondents profile

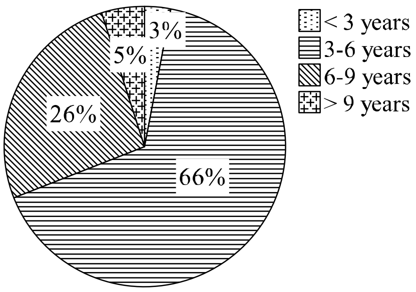
More than half (53%) of respondents in the survey are site engineers. Other respondents consist of project managers/ planners (9%), site managers (31%), and foremen (7%). The quite large proportion of top and functional managers confirms the reliability of collected data for identifying waste problems on the construction sites. The results are shown in Figure 5.2.



Party	Frequency	Percent
Owner	23	18.0
Consultant	26	20.0
Contractor	79	62.0

Figure 5.3 Party of respondents in project

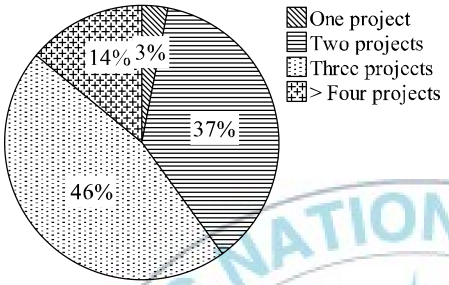
Regarding types of project stakeholder, 18% of respondents are owners, 20% of those are consultants, and 62% of those are contractors involving main contractors and subcontractors. The results are shown in Figure 5.3.



Year	Frequency	Percent
< 3	4	3.0
3-6	84	66.0
6-9	33	26.0
> 9	7	5.0

Figure 5.4 Years of experience

Majority (66%) of respondents have field experience of 3 to 6 years. Whereas, 3%, 26%, and 5% are respectively for less than or equal to 3 years, between 6 and 9 years, and 9 years or more. It would have been better if the proportion of respondents with 9 years or more could be increased. The results are shown in Figure 5.4.



Project	Frequency	Percent
1	4	3.0
2	47	37.0
3	59	46.0
> 4	18	14.0

Figure 5.5 Number of project involved

The proportion of respondents in terms of involvement in number of construction projects are: one project (3%), two projects (37%), three projects (46%), and more than or equal to four projects (14%). The results are shown in Figure 5.5.

This study also asked the respondents rate their level of concern about waste factors in construction projects based on their experience. The five-point Likert scale was assigned with a value being 1 for "much unattended" and 5 for "much attended". The result of analysis shows that the mean value is 3.54, and the standard deviation is 0.61. This proves that the respondents are quite concerned about waste problems in their construction projects. In overall, all above-mentioned results demonstrate that the collected data are appropriate to perform prospective analysis.

5.3.2 Waste recognition and control

5.3.2.1 Analysis on direct conversion wastes

Under this category, there are nine waste factors (see Table 3.2), which were asked to be identified by 128 respondents based on their own experience. For the total of 128 respondents and by calculation as 9x128, it sums up a total of 1,152 overall counts of inputs. For waste recognition, a total of 932 positive counts are recorded (or approximately 80.9%). It shows a quite high recognition on the waste concepts for the factors tested in this category. The detail of respondent's agreement for each factor is presented in Table 5.2. The results show that the maximum of waste recognition belongs to item Q1 *'over-allocated/ unnecessary equipment on site'* with 88.1%, and the minimum belongs to item Q6 *'material deteriorated/ damaged during construction periods'* with 74.3%.

Table 5.2 Recognition for direct conversion wastes

#	Factors	Agree (%)	Disagree (%)
Q1	Over-allocated/ unnecessary equipment on site	**88.1**	11.9
Q2	Over-allocated/ unnecessary materials on site	87.1	12.9
Q3	Over-allocated/ unnecessary workers on site	85.7	14.3
Q4	Unnecessary procedures and working protocols	87.1	12.9
Q5	Material lost/ stolen from site during construction period	83.1	16.9
Q6	Material deteriorated/ damaged during construction period	**74.3**	25.7
Q7	Mishandling or error in construction application/ installations	74.9	25.1
Q8	Materials for reworks/ repaired works/ defective works	82.9	17.1
Q9	Accidents on site	74.9	25.1

Similarly, for waste control, a total of 991 positive counts are recorded (or approximately 86.0%). It shows a high control ability on the waste factors tested. The detail of respondent's agreement for each factor is presented in Table 5.3. The results show that the maximum of waste control ability belongs to item Q8 *'materials for reworks/ repaired works/ defective works'* with 91.1%, and the minimum belongs to item Q6 *'material deteriorated/ damaged during construction periods'* with 83.6%.

Table 5.3 Control ability for direct conversion wastes

#	Factors	Agree (%)	Disagree (%)
Q1	Over-allocated/ unnecessary equipment on site	85.2	14.8
Q2	Over-allocated/ unnecessary materials on site	84.2	15.8
Q3	Over-allocated/ unnecessary workers on site	85.7	14.3
Q4	Unnecessary procedures and working protocols	84.7	15.3
Q5	Material lost/ stolen from site during construction period	85.7	14.3
Q6	Material deteriorated/ damaged during construction period	**83.6**	16.4
Q7	Mishandling or error in construction application/ installations	85.7	14.3
Q8	Materials for reworks/ repaired works/ defective works	**91.1**	8.9
Q9	Accidents on site	88.7	11.3

Table 5.4 Relationship between recognition and control ability of direct construction wastes

	Controlled	Not controlled	
Recognized	0.529	0.166	**0.695**
Not recognized	0.227	0.078	**0.305**
	0.756	**0.244**	**1.000**

By mixing the respondent's score of waste recognition with score of waste control ability will result in the crosstab as shown in Table 5.4. This table can be used to explain the inter-relationship between the waste recognition and the waste control ability. The results show that the relationship of recognition ability with control ability is quite low with 0.695 whether the wastes are controlled or not (include 0.529 for control and 0.166 for non-control).

5.3.2.2 Analysis on non-contributory time wastes

There are seven waste factors in this non-contributory time waste group (see Table 3.2). In the total of 128 respondents, by calculation as 7x128, it is equal to 896 counts of inputs. For waste recognition, a total of 726 positive counts are recorded (or approximately 81.0%). It shows a quite high recognition on the waste concepts in this category. The detail of respondent's agreement for each factor is presented in Table 5.5. The results show that the maximum of waste recognition belongs to item Q12 *'waiting for materials to be delivered on site'* with 89.2%, and the minimum belongs to item Q14 *'waiting for the clarification and confirmation by client and consultants'* with 62.7%.

Table 5.5 Recognition for non-contributory time wastes

#	Factors	Agree (%)	Disagree (%)
Q10	Waiting for others to complete their works before the proceeding works can be carried out	82.6	17.4
Q11	Waiting for equipment to be delivered on site	83.6	16.4
Q12	Waiting for materials to be delivered on site	89.2	10.8
Q13	Waiting for skilled workers to be provided on site	79.8	20.2
Q14	Waiting for the clarification and confirmation by client and consultants	**62.7**	37.3
Q15	Time for reworks/ repaired works/ defective works	**89.2**	10.8
Q16	Time for workers' rest during construction	86.2	13.8

For waste control, a total of 765 positive counts are recorded (or about 85.4%). It shows a high control ability on the waste factors in this group. The detail of respondent's agreement for each factor is presented in Table 5.6. The results show that the maximum of waste control ability belongs to item Q10 *'waiting for others to complete their works before the proceeding works can be carried out'* with 92.9%, and the minimum belongs to item Q13 *'waiting for skilled workers to be provided on site'* with 80.9%.

Table 5.6 Control ability for non-contributory time wastes

#	Factors	Agree (%)	Disagree (%)
Q10	Waiting for others to complete their works before the proceeding works can be carried out	**92.9**	7.1
Q11	Waiting for equipment to be delivered on site	87.7	12.3
Q12	Waiting for materials to be delivered on site	90.6	9.4
Q13	Waiting for skilled workers to be provided on site	**80.9**	19.1
Q14	Waiting for the clarification and confirmation by client and consultants	82.0	18.0
Q15	Time for reworks/ repaired works/ defective works	88.2	11.8
Q16	Time for workers' rest during construction	89.7	10.3

Table 5.7 Relationship between recognition and control ability of non-contributory time wastes

	Controlled	Not controlled	
Recognized	0.555	0.146	**0.701**
Not recognized	0.224	0.075	**0.299**
	0.779	**0.221**	**1.000**

The relationship crosstab for waste recognition and control in this group is shown in Table 5.7. The results show that the relationship between them is quite low with 0.701 whether the wastes are controlled or not (include 0.555 for control and 0.146 for non-control).

5.3.2.3 Analysis on contributory time wastes

There are three waste factors in this contributory time waste group (see Table 3.2). Similarly, in the total of 128 respondents, and by calculation as 3x128, it is equal to a score of 384. For waste recognition, a total of 238 positive counts are recorded (or approximately 62.0%). It shows a very low recognition on the these wastes. The detail of respondent's agreement for each factor is presented in Table 5.8. The results show that the maximum of waste recognition belongs to item Q17 *'time for supervising and inspecting the construction works'* with 67.7%, and the minimum belongs to item Q18 *'time for instructions and communication between engineers and workers'* with 57.3%.

Table 5.8 Recognition for contributory time wastes

#	Factors	Agree (%)	Disagree (%)
Q17	Time for supervising and inspecting the construction works	**67.7**	32.2
Q18	Time for instructions and communication between engineers and workers	**57.3**	42.7
Q19	Time for transporting workers, equipment and materials	64.2	35.8

For waste control, a total of 307 positive counts are recorded (or approximately 80.0%). It shows a quite high control ability on the waste factors in this group. The detail of respondent's agreement for each factor is presented in Table 5.9. The results show that the maximum of waste control ability belongs to item Q19 *'time for transporting workers, equipment and* *materials'* with 86.2%, and the minimum belongs to item Q17 *'time for supervising and inspecting the construction works'* with 76.9%.

Table 5.9 Control ability for contributory time wastes

#	Factors	Agree (%)	Disagree (%)
Q17	Time for supervising and inspecting the construction works	**76.9**	23.1
Q18	Time for instructions and communication between engineers and workers	79.2	20.8
Q19	Time for transporting workers, equipment and materials	**86.2**	13.8

The relationship crosstab for waste recognition and control in this group is shown in Table 5.10. The results show that the relationship between them is very low with 0.461 whether the wastes are controlled or not (include 0.310 for control and 0.151 for non-control).

Table 5.10 Relationship between recognition and control ability of contributory time wastes

	Controlled	Not controlled	
Recognized	0.310	0.151	**0.461**
Not recognized	0.365	0.174	**0.539**
	0.675	**0.325**	**1.000**

5.3.3 Correlation between recognition, control, and frequency of waste

Before analyzing data, score assignment for each set of data is required. It is an important process of conducting inferential analysis, especially for correlation analysis using Pearson coefficient, where aggregation of points are required for this research. For the recognition and control of waste, each positive answer is assigned with 2 points, and each negative answer is assigned with 1 point. Based on the waste categories in Table 3.2, the maximum point for direct conversion waste group (includes 9 factors) that can be aggregated for each case is equal to 18 points, and the minimum point is equal to 9 points.

Similarly, the maximum and minimum point for non-contributory time waste group (includes 7 factors) and contributory time waste group (include 3 factors) are 14 points and 7 points, and 6 points and 3 points, respectively. For the frequency of waste, points are ranged from 1 to 5 due to using five-point Likert scale; therefore, the maximum point that can be aggregated for direct conversion wastes is 45 points, and the minimum point is 9 points. Similarly, the maximum and minimum point for non-contributory time waste group and contributory time waste group are 35 points and 7 points, and 15 points and 3 points, respectively.

Table 5.11 Hypotheses about relationships between recognition, control, and frequency

No.	Item	Statement of hypothesis
1	Recognition – Control	There is a significant relationship between wastes perceived with tendency to control these waste
2	Recognition – Frequency	There is a significant relationship between wastes perceived with frequencies of occurrence of such wastes
3	Control – Frequency	There is a significant relationship between tendency to control wastes with frequencies of occurrence of such wastes

As mentioned above, the Pearson correlation analysis is used in this study. It is to test on three hypotheses to see whether any significant interrelationship existed between understanding of wastes, actual control ability of waste and frequency of waste occurrence for direct conversion waste group. These hypotheses are stated in Table 5.11. This analysis is also used for non-contributory time waste group and contributory time waste group. Therefore, there are a total of nine hypotheses tested.

Table 5.12 Correlation between recognition, control, and frequency of direct conversion waste group

		Recognition	Control	Frequency
Correlation coefficients		1	-0.056	-0.108
Significance level	Recognition	-	0.529	0.225
Number		128	128	128
Correlation coefficients			1	-0.084
Significance level	Control		-	0.344
Number			128	128
Correlation coefficients				1
Significance level	Frequency			-
Number				128

The results of Pearson analysis are shown in Table 5.12 for direct conversion waste group, in Table 5.13 for non-contributory time waste group, and in Table 5.14 for contributory time waste group. These results indicate that there are non-significant relationships between recognition and control, and between control and frequency for all three waste groups because the significance values (K) are greater than 0.05. Whereas, between recognition and frequency, there are non-significant correlations for direct conversion waste group (K = 0.225) and non-contributory time waste group (K = 0.553), but there is a significant negative correlation (r = -0.236) for contributory time waste group because K = 0.007 < 0.05. It means that only hypothesis on relationship between recognition and frequency of contributory time waste factors is accepted.

In general, these above results demonstrate that the waste factors are highly recognized by the respondents, but they are not probably required to control them due to there are no significant correlation between them, and vice versa.

Table 5.13 Correlation between recognition, control and frequency of non-contributory time waste group

		Recognition	Control	Frequency
Correlation coefficients		1	-0.041	0.053
Significance level	Recognition	-	0.649	0.553
Number		128	128	128
Correlation coefficients			1	-0.127
Significance level	Control		-	0.153
Number			128	128
Correlation coefficients				1
Significance level	Frequency			-
Number				128

Table 5.14 Correlation between recognition, control and frequency of contributory time waste group

		Recognition	Control	Frequency
Correlation coefficients		1	-0.073	-0.236
Significance level	Recognition	-	0.410	0.007
Number		128	128	128
Correlation coefficients			1	-0.102
Significance level	Control		-	0.253
Number			128	128
Correlation coefficients				1
Significance level	Frequency			-
Number				128

5.3.4 Ranking on waste factors

Frequency method was employed to find out the occurrences of waste factors. Mean values and standard deviations were then identified based on Eq. (3.1) and (3.2). A five-point Likert scale was assigned with a value being 1 for "never" and 5 for "very frequently". The results of analysis are shown in Table 5.15 with descending order. The results show that the standard deviations are quite large (approximately 0.9). It demonstrates that the data values from respondents were found to be scattered.

From the mean ranking results, it shows that the five top factors are contributed by all three waste groups. The factors of direct conversion waste are the first and second. They are item Q5 and Q6 *'material lost or deteriorated from site during construction period'*. This finding demonstrates that the wastes related to materials are the most concerned problem in high-rise building projects. Whereas, the third and fourth belong to the factor of contributory time waste. These wastes are item Q18 *'time for instructions and communication between engineers and workers'* and item Q17 *'time for supervising and inspecting the construction works'*. It can be easily seen that time for these activities is needed but it does not add any value to the completed work as stated in LC. Eventually, another fourth belongs to the factor of non-contributory time waste. That is item Q12 *'waiting time for materials to be delivered on site'*. Waiting time is definitely the waste because it never adds value to the completed work; therefore, it needs to be removed from the construction processes.

Less influencing on projects than previous wastes, items ranked from fifth to thirteenth are mainly contributed by non-contributory time wastes. Most of them are wastes related to waiting time involving item Q13 and Q11 *‘waiting for skilled workers and required equipment to be delivered on site’*, item Q14 *‘waiting for the clarification and confirmation by client or consultants’*, item Q10 *‘waiting for others to complete their works before the proceeding works can be carried out’*. Almost these types of waiting time are not necessary for performance processes; thus, they add no value to the completed work. Particularly, item Q15 *‘time for reworks’* (or repaired/ defective works) is clearly the waste in construction that has been reported in many previous studies. There are many sources of rework such as owner change, design error/ omission, design change, constructor’s error, and transportation error.

Finally, the five last factors mainly belong to the direct conversion wastes. These wastes are related to item Q2, Q1, Q3 *‘over-allocated or unnecessary materials, equipment, and workers on site’*, and item Q9 *‘accidents on site’*. This shows that most of construction resources are wasted with the lowest level in practice compared with others.

In general, the above results indicate that the main wastes belong to the direct conversion activities, and the workflow wastes of both non-contributory and contributory activities are still lower than the acceptable level of waste because most of them are located in the middle range of the ranking (value of 3 in the scale representing “seldom occurrence”). Therefore, the current process flows are quite smooth. Furthermore, the direct conversion wastes are solely related to manpower, materials, and equipment as classified by LC. These resources play a key role in production on construction sites. Four direct conversion wastes are ranked in range from the first to the tenth (two of them are the first and the second). Thus, the current performance process are significantly impacted by these wastes.

Table 5.15 Ranking of waste factors by frequency of occurrence

Rank	#	Waste factor	N	Mean	Std. Dev.
1	Q5	Material lost/ stolen from site during construction period	128	3.328	0.906
2	Q6	Material deteriorated/ damaged during construction period	128	3.320	0.896
3	Q18	Time for instructions and communication between engineers and workers	128	3.313	0.876
4	Q17	Time for supervising and inspecting the construction works	128	3.250	0.988
4	Q12	Waiting for materials to be delivered on site	128	3.250	0.988
5	Q13	Waiting for skilled workers to be provided on site	128	3.227	0.974
6	Q4	Unnecessary procedures and working protocols	128	3.203	0.983
7	Q7	Mishandling or error in construction application/ installations	128	3.195	0.852
8	Q19	Time for transporting workers, equipment and materials	128	3.180	0.976
9	Q11	Waiting for equipment to be delivered on site	128	3.156	0.846
10	Q14	Waiting for the clarification and confirmation by client and consultants	128	3.133	0.975
11	Q10	Waiting for others to complete their works before the proceeding works can be carried out	128	3.102	0.954
12	Q8	Materials for reworks/ repaired works/ defective works	128	3.031	0.887
13	Q15	Time for reworks/ repaired works/ defective works	128	2.984	0.887
14	Q2	Over-allocated/ unnecessary materials on site	128	2.969	1.011
15	Q1	Over-allocated/ unnecessary equipment on site	128	2.930	0.949
16	Q3	Over-allocated/ unnecessary workers on site	128	2.922	0.936
17	Q16	Time for workers' rest during construction	128	2.875	1.004
18	Q9	Accidents on site	128	2.820	0.909

5.3.5 Ranking on waste causes

Ranking on likeliness for the causes of waste was also identified by their frequency of occurrences in the practical construction performance. The purpose of this analysis is to determine the respondent's recognition of particular cause factors that cause construction wastes. It is same with the ranking of the frequency of waste occurrences above. This section used the four-point Likert scale ranging from 1 as most "unlikely" to 4 as "most likely". The results are shown in Table 5.16.

Table 5.16 Ranking of waste causes by frequency of occurrence

Rank	#	Waste factor	Total	Mean	Std. Dev.
1	A3	Lack of control	128	2.711	0.862
2	A2	Poor planning and scheduling	128	2.695	0.740
3	A4	Bureaucracy	128	2.688	0.847
3	B4	Too late supervision	128	2.688	0.801
4	B5	Poor worker/ equipment distribution	128	2.664	0.806
4	C1	Inappropriate construction methods	128	2.664	0.816
5	C3	Equipment shortage	128	2.602	0.854
6	C6	Poor site documentation	128	2.586	0.883
7	D5	Poor material handling on site	128	2.563	0.894
8	B2	Inexperience inspectors	128	2.547	0.831
9	D1	Poor material delivery schedule	128	2.523	0.803
10	C5	Poor site layout	128	2.516	0.842
11	D4	Poor storage of materials	128	2.508	0.763
12	B1	Lack of trade skills	128	2.500	0.699
12	D2	Poor quality of materials	128	2.500	0.842
13	E2	Late information and decision making	128	2.492	0.763
14	D3	Inappropriate/ misuse of materials	128	2.445	0.821
15	C2	Outdated equipment	128	2.438	0.771
16	B3	Too few supervisors/ foreman	128	2.430	0.791
17	C4	Poor equipment choice or ineffective equipment	128	2.398	0.807
18	A1	Poor coordination among project participants	128	2.383	0.824
18	E3	Unclear information	128	2.383	0.861
19	E1	Defective or wrong information	128	2.367	0.886

The three top causes belong to the management/ administration causes. The mean ranking results show that item A3 *'lack of control'* is highly regarded as the main contributory cause to the construction wastes with the highest mean value (μ = 2.711), and with respectively 0.016 and 0.023 from the second rank item A2 *'poor planning and scheduling'* and the third rank item A4 *'bureaucracy'*. The next two belong to the people causes. Those are item B4 *'too late supervision'* (μ = 2.688) and item B5 *'poor resource distribution'* (μ = 2.664).

Among the clusters of cause factors observed from Table 5.16, there are three categories of waste cause factors are widely acknowledged as the key contributory factors to construction wastes. Those categories include management/ administration factors, people factors, and execution/ performance factors because most of the cause factors captured under these three categories are rated with the mean over 2.5.

In overall, the likelihood of recognizing the items above as the causes of waste that can impact on the productivity of the project are reasonably high because most of the mean value for the items tested are clustering around 2.5 (value of 2 and 3 in the scale representing "unlikely" and "likely", respectively). However, there are also some exceptions such as item E3 *'unclear information'* and item E1 *'defective or wrong information'*. Both of them are recorded a slightly low mean values of 2.383 and 2.367, respectively.

5.3.6 Identification of main causes

The study also carried out an analysis to relate the particular causes to the waste factors. This is to give a better picture of what leads to the waste in construction processes as suggested by the respondents. This analysis method is called “cause-and-effect matrix”.

Table 5.17 Total of response value from respondents

#	Waste factor	Response value (%)				
		A	B	C	D	E
Q1	Over-allocated/ unnecessary equipment on site	75.8	14.1	3.9	4.7	1.6
Q2	Over-allocated/ unnecessary materials on site	47.7	27.3	10.2	9.4	5.5
Q3	Over-allocated/ unnecessary workers on site	57.8	18.8	9.4	8.6	5.5
Q4	Unnecessary procedures and working protocols	50.0	32.8	6.3	3.9	7.0
Q5	Material lost/ stolen from site during construction period	29.7	40.6	15.6	9.4	4.7
Q6	Material deteriorated/ damaged during construction period	25.0	37.5	18.8	10.9	7.8
Q7	Mishandling or error in construction applications/ installations	24.2	50.0	9.4	11.7	4.7
Q8	Materials for reworks/ repaired works/ defective works	36.7	33.6	13.3	7.0	9.4
Q9	Accidents on site	25.8	28.9	13.3	21.9	10.2
Q10	Waiting for others to complete their works before the proceeding works can be carried out	23.4	22.7	34.4	11.7	7.8
Q11	Waiting for equipment to be delivered on site	14.8	42.2	19.5	17.2	6.3
Q12	Waiting for materials to be delivered on site	13.3	27.3	34.4	18.8	6.3
Q13	Waiting for skilled workers to be provided on site	29.7	39.1	8.6	16.4	6.3
Q14	Waiting for the clarification and confirmation by client and consultants	29.7	32.8	14.1	14.1	9.4
Q15	Time for reworks/ repaired works/ defective works	25.0	28.1	27.3	11.7	11.7
Q16	Time for workers’ rest during construction	17.2	28.9	32.0	7.8	7.8
Q17	Time for supervising and inspecting the construction works	28.1	28.1	21.1	14.1	10.9
Q18	Time for instructions and communication between engineers and workers	23.4	28.9	17.2	22.7	7.8
Q19	Time for transporting workers, equipment and materials	21.9	21.1	13.3	35.9	7.8

Note: A: management/ administration causes; B: people causes; C: execution/ performance causes, D: material causes; and E: information/ communication causes

The relationship between waste causes and waste itself was identified through one-by-one connection. The major cause was then identified by the item which accounted for maximum value of response. The total of value of response from respondents is shown in Table 5.17. For example, the detailed results of connecting the waste Q1 to five cause groups are as follows: 97 responses for management/ administration cause in a total of 128 responses (75.8%), and 18, 5, 6 and 2 responses for people cause (14.1%), execution/ performance cause (3.9%), material cause (4.7%) and information/ communication cause (1.6%), respectively. Thus, the main cause for waste Q1 belongs to the management/ administration cause group.

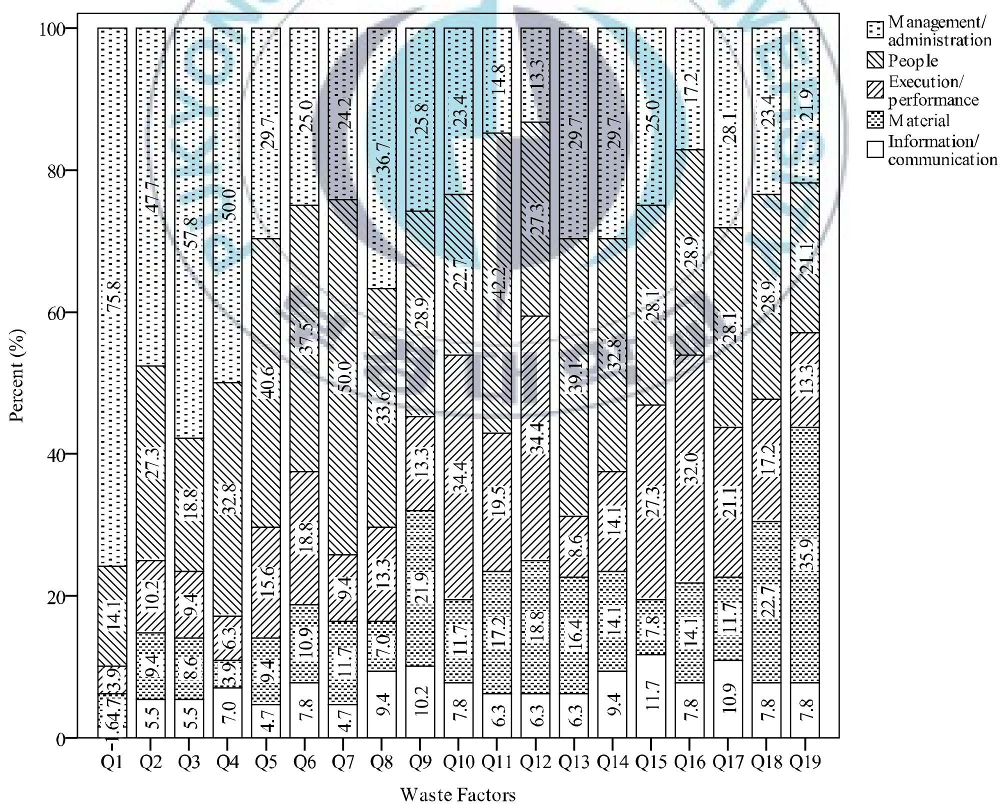


Figure 5.6 Cause-and-effect relationship matrix

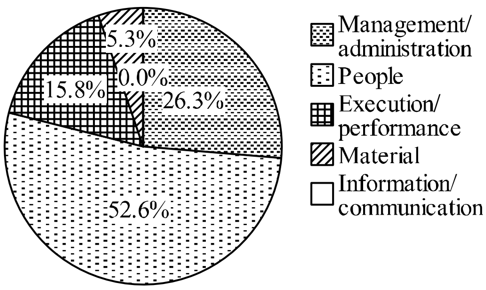
Table 5.18 Summary of connection results

#	Waste factor	Cause group	Max (%)
Q1	Over-allocated/ unnecessary equipment on site	A	75.8
Q2	Over-allocated/ unnecessary materials on site	A	47.7
Q3	Over-allocated/ unnecessary workers on site	A	57.8
Q4	Unnecessary procedures and working protocols	A	50.0
Q5	Material lost/ stolen from site during construction period	B	40.6
Q6	Material deteriorated/ damaged during construction period	B	37.5
Q7	Mishandling or error in construction applications/ installations	B	50.0
Q8	Materials for reworks/ repaired works/ defective works	A	36.7
Q9	Accidents on site	B	28.9
Q10	Waiting for others to complete their works before the proceeding works can be carried out	C	34.4
Q11	Waiting for equipment to be delivered on site	B	42.2
Q12	Waiting for materials to be delivered on site	C	34.4
Q13	Waiting for skilled workers to be provided on site	B	39.1
Q14	Waiting for the clarification and confirmation by client and consultants	B	32.8
Q15	Time for reworks/ repaired works/ defective works	B	28.1
Q16	Time for workers' rest during construction	C	32.0
Q17	Time for supervising and inspecting the construction works	B	28.1
Q18	Time for instructions and communication between engineers and workers	B	28.9
Q19	Time for transporting workers, equipment and materials	D	35.9

Note: A: management/ administration causes; B: people causes; C: execution/ performance causes, D: material causes; and E: information/ communication causes

Figure 5.6 is the overall analysis on cause-and-effect matrix of the major causes to the construction wastes. Table 5.18 presents the main cause for each waste factor which is deduced from Figure 5.6. Since then, the dominant cause is identified through counting number of main causes for all waste factors based on Table 5.18. These results are shown in Figure 5.7. The results indicate that the dominant cause belongs to the people cause with 52.6%

(score 10 of total 19), and the most unlikely cause belongs to the information/ communication cause with 0% (score 0 of total 19).



Group	Count	Percent
Management/ Administration	5	26.3
People	10	52.6
Execution/ Performance	3	15.8
Material	1	5.3
Information/ Communication	0	0.0

Figure 5.7 Proportion of main causes for waste factors

5.3.7 Latent relationship between waste factors

Table 5.19 presents the correlation matrix for waste factors. There are many correlation coefficients significant at level of 0.05. It is concluded that there are sufficient correlations in data matrix to justify that the application of factor analysis is possible.

Factor analysis technique was employed in this study to see the latent relationship between waste factors. Rotation method is *varimax* with Kaiser normalization. Before applying the factor analysis technique, the suitability of data must be enquired. In this regard, Barlett's test of sphericity having significance at 0.000 indicates that the correlation matrix is not an identity matrix. Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is sufficient with the value of 0.851 (see Table 5.20). Both of two parameters justify that the factor analysis can be applicable. All nineteen waste factors are appropriate for factor analysis because their communalities are higher than 0.5 (see Table 5.21). By using latent root criterion, five factors can be extracted with eigenvalues greater than 1.0.

Table 5.19 Correlation matrix

Waste factor	Q1	Q2	Q3	Q4	Q5	…	Q17	Q18	Q19
Q1	1.000	0.523	0.517	0.395	**0.229**	…	**0.271**	0.263	**0.167**
Q2	0.523	1.000	0.472	0.363	**0.132**	…	0.307	0.233	0.173
Q3	0.517	0.472	1.000	**0.257**	**0.170**	…	0.260	**0.184**	**0.188**
Q4	0.395	0.363	**0.257**	1.000	0.349	…	0.393	0.282	0.241
Q5	**0.229**	**0.132**	**0.170**	0.349	1.000	…	0.251	**0.138**	0.352
Q6	0.221	0.228	**0.162**	0.444	0.384	…	0.327	0.223	0.294
Q7	0.329	0.318	0.375	0.310	0.273	…	0.288	**0.097**	**0.137**
Q8	**0.302**	0.387	0.259	0.309	0.301	…	0.332	0.220	0.294
Q9	0.232	0.311	0.335	**0.182**	**0.110**	…	**0.173**	0.239	0.259
Q10	0.277	0.256	**0.141**	0.356	0.371	…	0.307	0.169	0.285
Q11	0.308	0.291	0.195	0.407	0.344	…	0.339	0.274	0.300
Q12	**0.178**	0.236	0.158	0.328	0.312	…	0.419	0.255	0.182
Q13	0.290	0.207	**0.123**	0.305	0.201	…	0.309	0.332	0.230
Q14	0.180	0.204	0.322	0.210	0.298	…	0.284	0.255	0.314
Q15	0.270	0.307	0.274	**0.148**	**0.183**	…	**0.166**	**0.118**	0.194
Q16	0.197	**0.120**	0.191	**0.058**	0.193	…	**0.056**	**0.143**	0.200
Q17	**0.271**	0.307	0.260	0.393	0.251	…	1.000	**0.182**	0.223
Q18	0.263	0.233	**0.184**	0.282	**0.138**	…	**0.182**	1.000	0.330
Q19	**0.167**	0.173	**0.188**	0.241	0.352	…	0.223	0.330	1.000

Note: Bold value is significant at 0.05

Table 5.20 KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.851
Bartlett's Test of Sphericity	Approx. Chi-Square	657.365
	df	171
	Sig.	0.000

Table 5.21 Communalities

#	Waste factors	Initial	Extraction
Q1	Over-allocated/ unnecessary equipment on site	1.000	0.648
Q2	Over-allocated/ unnecessary materials on site	1.000	0.644
Q3	Over-allocated/ unnecessary workers on site	1.000	0.631
Q4	Unnecessary procedures and working protocols	1.000	0.522
Q5	Material lost/ stolen from site during construction period	1.000	0.599
Q6	Material deteriorated/ damaged during construction period	1.000	0.552
Q7	Mishandling or error in construction applications/ installations	1.000	0.638
Q8	Materials for reworks/ repaired works/ defective works	1.000	0.530
Q9	Accidents on site	1.000	0.583
Q10	Waiting for others to complete their works before the proceeding works can be carried out	1.000	0.527
Q11	Waiting for equipment to be delivered on site	1.000	0.591
Q12	Waiting for materials to be delivered on site	1.000	0.607
Q13	Waiting for skilled workers to be provided on site	1.000	0.670
Q14	Waiting for the clarification and confirmation by client and consultants	1.000	0.604
Q15	Time for reworks/ repaired works/ defective works	1.000	0.545
Q16	Time for workers' rest during construction	1.000	0.619
Q17	Time for supervising and inspecting the construction works	1.000	0.534
Q18	Time for instructions and communication between engineers and workers	1.000	0.517
Q19	Time for transporting workers, equipment and materials	1.000	0.522

Extraction Method: Principal component analysis

Figure 5.8 is the scree plot of nineteen items as mentioned in previous section. Statistics of variance explained before and after rotation are shown in Table 5.22 and Table 5.23, respectively. With five extracted factors, 56.7% of variance is accounted for the waste factors in construction projects. Table 5.24 shows the five factor loadings extracted from factor analysis technique except for loading values less than 0.5. The varimax orthogonal rotation of principal component analysis is used to group factors. These five factors are named as PC1, PC2, PC3, PC4 and PC5.

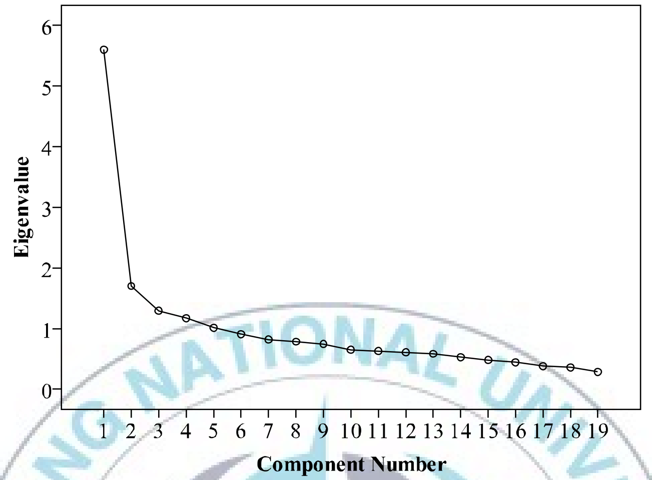


Figure 5.8 Scree plot of waste factors

Component PC1, called "resource plan and storage", consists of seven initial factors that are mainly related to contractor. Waiting for others to complete their works is a kind of non-contributory time wastes under the recognition of lean production. In construction project, activities are planned according to their precedence and resource constraints. If an activity is not finished as planned, a next rearward activity cannot be started. Waiting for equipment, materials and skilled workers to be delivered on site are the most common problem in construction projects in Vietnam. This is mainly due to poor supply plan between contractor/ subcontractors with suppliers. Normally, suppliers involve in project to provide equipment and/or materials with reasonable price, and propose an appropriate method to construct them on site as well. However, the schedule for delivering those equipment and materials to site is often delayed because it is affected by many unforeseeable causes during construction such as inflation, owner-related design changes, poor communication between parties, lack of traffic investigation, and shortage of raw materials. Materials are often damaged or lost from site during construction period. This is due to poor material protection system by contractor or subcontractors. Construction project often requires a large number of materials and labors. Many of materials are very easy to be broken if having no careful storage. One of contributory activities in construction projects is supervision or inspection for the executing works. Professionals in construction industry have thought that this activity is a required activity for doing the work. Thus, they have not recognized it as a waste that needs to be reduced or eliminated under the viewpoint of lean production.

Table 5.22 Total variance explained before rotation

Component	Initial eigenvalues		
	Total	% of variance	Cumulative %
1	5.601	29.480	29.480
2	1.703	8.965	38.445
3	1.293	6.805	45.250
4	1.171	6.164	51.414
5	1.012	5.328	56.742
6	0.909	4.787	61.529
7	0.821	4.320	65.849
8	0.785	4.131	69.980
9	0.747	3.932	73.912
10	0.650	3.421	77.333
11	0.632	3.326	80.659
12	0.608	3.198	83.856
13	0.586	3.082	86.938
14	0.528	2.780	89.718
15	0.483	2.541	92.259
16	0.445	2.345	94.603
17	0.381	2.004	96.607
18	0.360	1.894	98.501
19	0.285	1.499	100.000

Extraction method: Principal component analysis

Table 5.23 Total variance explained after rotation

Component	Extraction Sums of Squared Loadings		
	Total	% of variance	Cumulative %
1	3.302	17.377	17.377
2	2.529	13.311	30.688
3	1.766	9.295	39.983
4	1.665	8.763	48.746
5	1.519	7.996	56.742
6-19			

Extraction method: Principal component analysis

Component PC2, called "resource distribution and usage", includes four initial factors that are mainly related to the contractor's resource distribution during construction phase. Traditionally, quantity of materials, labor and equipment is defined based on drawings and specification for construction. A good resource plan is a plan that help general contractor or subcontractors provide the required resources on time and with exact quantity. Under the philosophies of lean production in construction, over-allocating resource is considered as a waste because it leads to status of inventory, deterioration and mess on site. Furthermore, unnecessary resources should be eliminated to reduce the cost for owner and contractor. Poor management or errors during construction installation is a cause for over-allocation of resource. This is an unavoidable phenomenon because there is no perfect method of construction in practice.

Component PC3, called "working procedure", comprises two initial factors that are related to working procedures. In the construction industry in Vietnam, unnecessary working procedures and protocols exist in the current performance as an inherent characteristic. They often cause waste in terms of cost and time because they add no value to the final product. Therefore, many attempts on reducing them have been made in practice to “lean” the performance processes. Lengthy or complex procedure of information clarification and confirmation by client and consultants is one of evidence for excusable construction delays of contractor. It is most likely to happen when there are errors or unclear information in design drawings and specification.

Component PC4, called “communication and transport”, involves two initial factors that are related to time for communication and transport on site. Both of them belong to contributory time waste group under classification of lean production. Instruction and communication between engineers and workers is a needed action before and during performance. At the same time, materials and equipment are provided so that the work can be started. However, one of most common problems in construction projects is that time for transporting these materials and equipment to the expected place is quite long due to tower crane’s bad operation. In order to prevent this problem, the managers should make a suitable plan for distributing materials to each worker team according to its priority.

Component PC5, called “worker’s rest”, only contains one initial factor that is related to resting time of workers. Lean production suggests that work flows are continuous. Consequentially, when workers take rest, the work flow is likely to be interrupted. One of most used methods to prevent this interruption is working in shifts. Moreover, dividing the work logically is a good way to reduce the stresses for workers, thus production efficiency may be increased.

Table 5.24 Factor analysis loading results

#	Waste factors	Extracted factors				
		PC1	PC2	PC3	PC4	PC5
Q10	Waiting for others to complete their works before the proceeding works can be carried out	0.705				
Q11	Waiting for equipment to be delivered on site	0.651				
Q6	Materials deteriorated/ damaged during construction period	0.645				
Q5	Materials lost/ stolen from site during construction period	0.627				
Q12	Waiting for materials to be delivered on site	0.589				
Q13	Waiting for skilled workers to be provided on site	0.562				
Q17	Time for supervising and inspecting the construction works	0.513				
Q2	Over-allocated/ unnecessary materials on site		0.744			
Q3	Over-allocated/ unnecessary workers on site		0.731			
Q1	Over-allocated/ unnecessary equipment on site		0.714			
Q7	Mishandling or error in construction applications/ installation		0.505			
Q4	Unnecessary working procedures and protocols			0.760		
Q14	Waiting for the clarification and confirmation by client and consultants			0.654		
Q18	Time for instructions and communication between engineers and workers				0.675	
Q19	Time for transporting workers, equipment and materials				0.607	
Q16	Time for worker's rest during construction					0.771
Q8	Materials for reworks/ repaired works/ defective works [a]					
Q15	Time for reworks/ repaired works/ defective works [a]					
Q9	Accidents on site [a]					

Extraction method: Principal component analysis.
Rotation method: Varimax with Kaiser normalization. It is converged in 8 iterations.
[a]: loading less than 0.5

5.3.8 Evaluation of waste level

Based on the results of factor analysis, the waste level of the construction industry can be evaluated. There are five components, i.e., PC1, PC2, PC3, PC4 and PC5. Variables clustered in one component were collapsed, and a new response rating was calculated for each respondent. The mean and standard deviation for each component are shown in Table 5.25.

Table 5.25 Descriptive statistics of principal components

Component	Mean	Std. Deviation	N
PC1	3.03	0.516	128
PC2	3.05	0.691	128
PC3	3.60	0.632	128
PC4	3.14	0.628	128
PC5	3.24	0.649	128

Pearson correlation analysis was then employed to identify the correlative strength between these five components. The result is shown in Table 5.26. It indicates that there is significant positive correlation between them. Thus, these can be represented as construction waste factors.

Table 5.26 Correlation coefficients of principal components

Component	PC1	PC2	PC3	PC4	PC5
PC1	1.000	0.626	0.628	0.649	0.595
PC2	0.626	1.000	0.631	0.689	0.528
PC3	0.628	0.631	1.000	0.629	0.480
PC4	0.649	0.689	0.629	1.000	0.466
PC5	0.595	0.528	0.480	0.466	1.000
Sum	**3.498**	**3.474**	**3.368**	**3.433**	**3.069**

Correlation is significant at 0.01 level (2-tailed)

Correlation strength has been adopted to calculate the individual weight of principal components. Rationale to employ correlation coefficient as a weighting criterion is that a more correlative power of a factor will have the highest effect to the overall waste level. Weight of each component is calculated by dividing its value of correlation coefficient by total value of all coefficients. The results are shown in Table 5.27.

Table 5.27 Weight of principal components

Component	Coefficient	Weight
PC1	3.498	0.218
PC2	3.474	0.205
PC3	3.368	0.214
PC4	3.433	0.211
PC5	3.069	0.152
Total	**16.842**	**1.000**

This study has revealed five significant waste measuring factors. All the five factors are self explanatory criteria of waste evaluation. Sixteen elements as shown in Table 5.24 define these five factors. These sixteen numbers of sub elements are completely agreed by the construction professionals based on their experience. Therefore, the waste measuring results can be assured of the high level of quality. The weight of elements of each component is defined based on loading results as shown in Table 5.28.

The criterion used in this study to assess the practical level of waste occurrence level is: (1) very low (0-20), (2) fairly low (21-40), (3) moderate (41-60), (4) fairly high (61-80), and (5) very high (81-100). Based on the results in Table 5.15, the mean of frequency of occurrence of each initial waste factor has been identified by five-point Likert scale with a value being

1 for "never" and 5 for "very frequently". As a result, the conversion ratio between these two scales is 20. The results of field evaluation for each factor are shown in Table 5.29.

Table 5.28 Weight of elements of each component

#	Elements	Loading results	Weight
	PC1 "Resource plan and storage"	**4.292**	**1.000**
Q10	Waiting for others to complete their works before the proceeding works can be carried out	0.705	0.164
Q11	Waiting for equipment to be delivered on site	0.651	0.152
Q6	Materials deteriorated/ damaged during construction period	0.645	0.150
Q5	Materials lost/ stolen from site during construction period	0.627	0.146
Q12	Waiting for materials to be delivered on site	0.589	0.137
Q13	Waiting for skilled workers to be provided on site	0.562	0.131
Q17	Time for supervising and inspecting the construction works	0.513	0.120
	PC2 "Resource distribution and usage"	**2.694**	**1.000**
Q2	Over-allocated/ unnecessary materials on site	0.744	0.276
Q3	Over-allocated/ unnecessary workers on site	0.731	0.271
Q1	Over-allocated/ unnecessary equipment on site	0.714	0.265
Q7	Mishandling or error in construction application/ installations	0.505	0.188
	PC3 "Working procedure"	**1.414**	**1.000**
Q4	Unnecessary working procedures and protocols	0.760	0.537
Q14	Waiting for the clarification and confirmation by client and consultants	0.654	0.463
	PC4 "Communication and transport"	**1.282**	**1.000**
Q18	Time for instructions and communication between engineers and workers	0.675	0.527
Q19	Time for transporting workers, equipment and materials	0.607	0.473
	PC5 "Worker's rest"	**0.771**	**1.000**
Q16	Time for workers' rest during construction	0.771	1.000

Table 5.29 Value of respondents' field evaluation

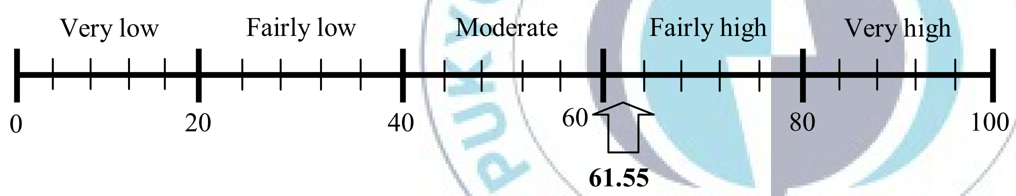
#	Waste factor	Mean	Ratio	Field evaluation
Q1	Over-allocated/ unnecessary equipment on site	2.930	20	58.60
Q2	Over-allocated/ unnecessary materials on site	2.969	20	58.78
Q3	Over-allocated/ unnecessary workers on site	2.922	20	58.44
Q4	Unnecessary procedures and working protocols	3.203	20	64.06
Q5	Material lost/ stolen from site during construction period	3.328	20	66.56
Q6	Material deteriorated/ damaged during construction period	3.320	20	66.40
Q7	Mishandling or error in construction application/ installations	3.195	20	63.90
Q8	Materials for reworks/ repaired works/ defective works	3.031	20	60.62
Q9	Accidents on site	2.820	20	56.40
Q10	Waiting for others to complete their works before the proceeding works can be carried out	3.102	20	62.04
Q11	Waiting for equipment to be delivered on site	3.156	20	63.12
Q12	Waiting for materials to be delivered on site	3.250	20	65.00
Q13	Waiting for skilled workers to be provided on site	3.227	20	64.54
Q14	Waiting for the clarification and confirmation by client and consultants	3.133	20	62.66
Q15	Time for reworks/ repaired works/ defective works	2.984	20	59.68
Q16	Time for workers' rest during construction	2.875	20	57.50
Q17	Time for supervising and inspecting the construction works	3.250	20	65.00
Q18	Time for instructions and communication between engineers and workers	3.313	20	66.26
Q19	Time for transporting workers, equipment and materials	3.180	20	63.60

Predicting weight of each element of components that is called "Waste Occurrence Level Indicator" (WOLI) was determined according to the element's loading proportion in a particular factor. The results of WOLI weightings and nature of measurement are given in Table 5.30.

Table 5.30 Evaluation sheet of WOLI for the construction industry

SN	No.	Principal components	Weight	Field evaluation (0-100)	Field score (3)x(4)	Overall waste score	Remark
(0)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	PC1	***Resource plan and storage***	**0.218**	**-**	**64.54**	**14.07**	
1	Q10	Waiting for others to complete their works before the proceeding works can be carried out	0.164	62.04	10.17		Qualitative
2	Q11	Waiting for equipment to be delivered on site	0.152	63.12	9.59		Qualitative
3	Q6	Material deteriorated/ damaged during construction periods	0.150	66.40	9.96		Qualitative
4	Q5	Material lost/ stolen from site during construction periods	0.146	66.56	9.72		Qualitative
5	Q12	Waiting for materials to be delivered on site	0.137	65.00	8.91		Qualitative
6	Q13	Waiting for skilled workers to be provided on site	0.131	64.06	8.39		Qualitative
7	Q17	Time for supervising and inspecting the construction works	0.120	65.00	7.80		Qualitative
	PC2	***Resource distribution and usage***	**0.205**	**-**	**59.60**	**12.22**	
1	Q2	Over-allocated/ unnecessary materials on site	0.276	58.78	16.22		Qualitative
2	Q3	Over-allocated/ unnecessary workers on site	0.271	58.44	15.84		Qualitative
3	Q1	Over-allocated/ unnecessary equipment on site	0.265	58.60	15.53		Qualitative
4	Q7	Mishandling or error in construction application/ installations	0.188	63.90	12.01		Qualitative
	PC3	***Working procedure***	**0.214**	**-**	**65.34**	**13.98**	
1	Q4	Unnecessary working procedures and protocols	0.537	64.54	34.66		Qualitative
2	Q14	Waiting for the clarification and confirmation by client and consultants	0.463	66.26	30.68		Qualitative

SN	No.	Principal components	Weight	Field evaluation (0-100)	Field score (3)x(4)	Overall waste score	Remark
	PC4	***Communication and transport***	**0.211**	**-**	**59.70**	**12.60**	
1	Q18	Time for instructions and communication between engineers and workers	0.527	62.66	33.02		Qualitative
2	Q19	Time for transporting workers, equipment and materials	0.473	56.40	26.68		Qualitative
	PC5	***Worker's rest***	**0.151**	**-**	**57.50**	**8.68**	
1	Q16	Time for workers' rest during construction	1.000	57.50	57.50		Qualitative
		GRAND TOTAL				**61.55**	
		REULTS				**Fairly high**	



<u>Reviewed by:</u>
Name:
Designation:
Organization name:
Date:
Comments:

5.3.9 Prediction of impact of wastes on project cost

5.3.9.1 By linear regression

Linear regression (LR) was used to develop a model to predict the effect of waste factors on project performance cost as stated in the fourth objective of this study. The independent variables (Q_i) are nineteen waste factors as mentioned in Table 3.2, and the dependent variable (Y) is the increased project performance cost due to these wastes based on respondents' feedback. Because the number of independent variables is larger than one, the multiple linear regression method is adopted in this study.

Table 5.31 Descriptive statistics of data sets

	N	Min	Max	Mean	Std. Dev.
Q1	128	1.00	5.00	2.93	.949
Q2	128	1.00	5.00	2.97	1.011
Q3	128	1.00	5.00	2.92	.936
Q4	128	1.00	5.00	3.20	.983
Q5	128	1.00	5.00	3.33	.906
Q6	128	1.00	5.00	3.32	.896
Q7	128	1.00	5.00	3.20	.852
Q8	128	1.00	5.00	3.03	.887
Q9	128	1.00	5.00	2.82	.909
Q10	128	1.00	5.00	3.10	.954
Q11	128	1.00	5.00	3.16	.846
Q12	128	1.00	5.00	3.25	.988
Q13	128	1.00	5.00	3.23	.974
Q14	128	1.00	5.00	3.13	.975
Q15	128	1.00	5.00	2.98	.887
Q16	128	1.00	5.00	2.88	1.004
Q17	128	1.00	5.00	3.25	.988
Q18	128	1.00	5.00	3.31	.876
Q19	128	1.00	5.00	3.18	.976
Project cost loss (Y)	128	5.00	15.00	9.36	1.561

Table 5.32 Linear regression model summary

Model	R	R^2	Adj. R^2	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.893[a]	.798	.763	.260	.798	22.492	19	108	.000

a. Predictors: (Constant), Q19, Q7, Q15, Q12, Q13, Q16, Q9, Q14, Q1, Q18, Q6, Q5, Q17, Q10, Q8, Q4, Q2, Q3, Q11
b. Dependent Variable: Y

Table 5.33 ANOVA results of linear analysis

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.977	19	1.525	22.492	.000[a]
	Residual	7.323	108	.068		
	Total	36.300	127			

The descriptive statistics of model are shown in Table 5.31. The model summary is shown in Table 5.32. It indicates that the R-squared of the LR model is 78.9%. Moreover, the results of prediction by LR is significant as shown in Table 5.33. The parameters of the LR model are shown in Table 5.34. The residuals statistics are shown in Table 5.35. The results of prediction show that the mean of predicted values is 9.36 with the standard deviation of 0.478 and the standard error (SE) of 10.1%. The detailed prediction values are available at the Appendix 2. As a rule of thumb, the accuracy of LR model is appropriate. Figure 5.9 shows the histogram of frequency and regression standardized residuals. It can be easily seen that the distribution of residuals is similar to the normal distribution. Figure 5.10 shows the straight relationship between expected and observed cumulative probability.

Table 5.34 Linear regression coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	7.134	.154		46.369	.000	6.829	7.439
Q1	-.056	.033	-.100	-1.703	.091	-.122	.009
Q2	.050	.031	.095	1.642	.103	-.010	.111
Q3	-.031	.033	-.054	-.936	.351	-.097	.035
Q4	.061	.030	.112	2.013	.047	.001	.120
Q5	-.065	.031	-.110	-2.072	.041	-.127	-.003
Q6	.162	.032	.271	5.008	.000	.098	.226
Q7	.234	.033	.373	7.068	.000	.168	.300
Q8	.076	.033	.126	2.266	.025	.009	.142
Q9	.069	.030	.118	2.324	.022	.010	.129
Q10	.012	.030	.022	.399	.691	-.048	.072
Q11	-.043	.039	-.068	-1.111	.269	-.120	.034
Q12	.116	.031	.214	3.780	.000	.055	.176
Q13	-.043	.029	-.078	-1.485	.140	-.100	.014
Q14	.097	.031	.177	3.182	.002	.037	.158
Q15	.116	.030	.192	3.883	.000	.057	.175
Q16	-.073	.025	-.136	-2.857	.005	-.123	-.022
Q17	.134	.029	.248	4.692	.000	.077	.191
Q18	-.074	.031	-.122	-2.423	.017	-.135	-.014
Q19	-.040	.028	-.073	-1.409	.162	-.096	.016

Stepwise regression analysis was then adopted to find out the possible regression models in which the choice of predictive variables is carried out by an automatic procedure. Usually, this takes the form of a sequence of F-tests (Draper and Smith, 1981). The frequent practice of fitting the final selected model followed by reporting estimates and confidence intervals without adjusting them to take the model building process into account has led to calls to stop using stepwise model building altogether, or to at least make sure model uncertainty is correctly reflected (Harrell, 2001).

Table 5.35 Residuals statistics of linear analysis

	Min	Max	Mean	Std. Deviation	N
Predicted Value	8.0303	10.3993	9.3625	.47766	128
Std. Predicted Value	-2.789	2.171	.000	1.000	128
Standard Error of Predicted Value	.059	.153	.101	.020	128
Adjusted Predicted Value	7.8208	10.4683	9.3572	.48964	128
Residual	-.60064	.66972	.00000	.24013	128
Std. Residual	-2.307	2.572	.000	.922	128
Stud. Residual	-2.448	2.947	.009	1.014	128
Deleted Residual	-.67663	.87917	.00529	.29162	128
Stud. Deleted Residual	-2.507	3.059	.010	1.024	128
Mahal. Distance	5.623	42.961	18.852	7.556	128
Cook's Distance	.000	.136	.011	.020	128
Centered Leverage Value	.044	.338	.148	.059	128

a. Dependent Variable: Y

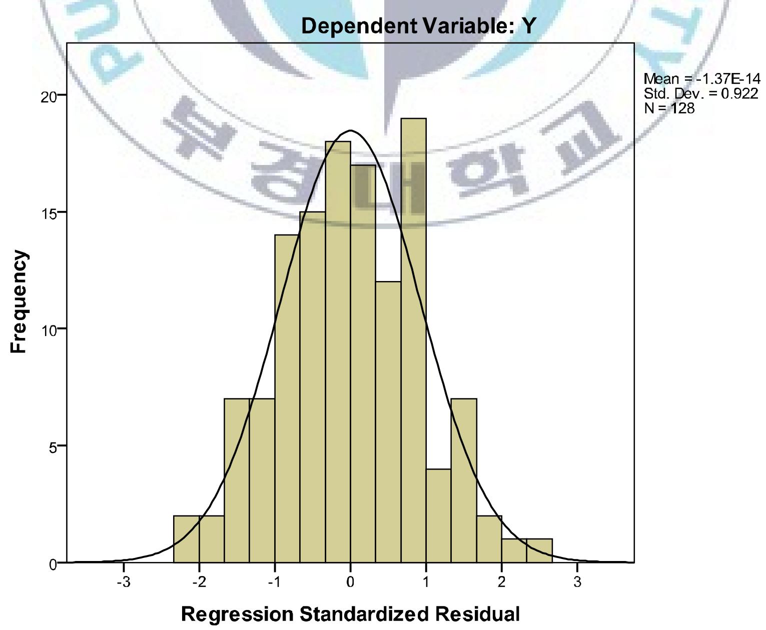


Figure 5.9 Histogram of linear analysis

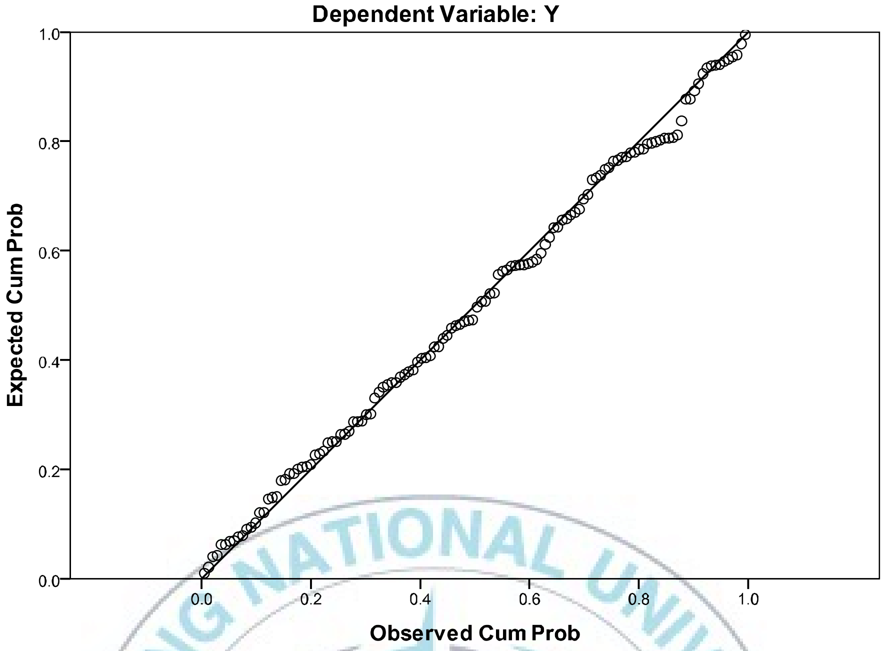


Figure 5.10 Normal P-P plot of linear regression standardized residual

Table 5.36 presents the variables that are entered or removed in the possible models. The results show that there are a total of eleven models considered based on the criteria: probability-of-F-to-enter is <= 0.050 and probability-of-F-to-remove is >= 0.100.

Table 5.37 presents the summary for all eleven possible regression models. The results show that the R^2 of the models change from 35.5% (one variable) to 76.8% (eleven variables). Moreover, the ANOVA results show that the prediction by each regression model is significant as presented in Table 5.38.

Table 5.39 presents the coefficients of eleven possible linear regression models. The residuals statistics are shown in Table 5.40. The results of prediction show that the mean of predicted values is 9.36 with the standard deviation of 0.469 and the standard error of 8.1%.

Table 5.36 Variables entered or removed

Model	Variables Entered	Variables Removed	Method
1	Q17		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Q7		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	Q6		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
4	Q12		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
5	Q15		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
6	Q16		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
7	Q14		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
8	Q18		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
9	Q9		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
10	Q5		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
11	Q8		.Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Y

The histogram of frequency and regression standardized residual in stepwise analysis is shown in Figure 5.11. It is easy to see that this distribution is most likely to normal distribution. Moreover, the relationship between expected and observed cumulative probability is straight as shown in Figure 5.12.

Table 5.37 Stepwise regression model summary

Model	R	R^2	Adj. R^2	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.596[a]	.355	.350	.43092	.355	69.488	1	126	.000
2	.732[b]	.536	.528	.36716	.180	48.561	1	125	.000
3	.777[c]	.604	.594	.34061	.068	21.241	1	124	.000
4	.808[d]	.653	.641	.32015	.049	17.356	1	123	.000
5	.826[e]	.682	.669	.30757	.029	11.273	1	122	.001
6	.839[f]	.703	.688	.29843	.021	8.586	1	121	.004
7	.849[g]	.721	.704	.29063	.018	7.583	1	120	.007
8	.857[h]	.735	.717	.28438	.014	6.331	1	119	.013
9	.865[i]	.749	.729	.27809	.014	6.440	1	118	.012
10	.871[j]	.758	.738	.27375	.010	4.774	1	117	.031
11	.877[k]	.768	.746	.26927	.010	4.925	1	116	.028

a. Predictors: (Constant), Q17
b. Predictors: (Constant), Q17, Q7
c. Predictors: (Constant), Q17, Q7, Q6
d. Predictors: (Constant), Q17, Q7, Q6, Q12
e. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15
f. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15, Q16
g. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15, Q16, Q14
h. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15, Q16, Q14, Q18
i. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15, Q16, Q14, Q18, Q9
j. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15, Q16, Q14, Q18, Q9, Q5
k. Predictors: (Constant), Q17, Q7, Q6, Q12, Q15, Q16, Q14, Q18, Q9, Q5, Q8
l. Dependent Variable: Y

Table 5.38 ANOVA results of stepwise analysis

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28.977	19	1.525	22.492	.000[a]
	Residual	7.323	108	.068		
	Total	36.300	127			
2	Regression	19.449	2	9.725	72.140	.000[b]
	Residual	16.851	125	.135		
	Total	36.300	127			
3	Regression	21.914	3	7.305	62.961	.000[c]
	Residual	14.386	124	.116		
	Total	36.300	127			
4	Regression	23.693	4	5.923	57.788	.000[d]
	Residual	12.607	123	.102		
	Total	36.300	127			
5	Regression	24.759	5	4.952	52.346	.000[e]
	Residual	11.541	122	.095		
	Total	36.300	127			
6	Regression	25.524	6	4.254	47.765	.000[f]
	Residual	10.776	121	.089		
	Total	36.300	127			
7	Regression	26.164	7	3.738	44.252	.000[g]
	Residual	10.136	120	.084		
	Total	36.300	127			
8	Regression	26.676	8	3.335	41.232	.000[h]
	Residual	9.624	119	.081		
	Total	36.300	127			
9	Regression	27.174	9	3.019	39.042	.000[i]
	Residual	9.126	118	.077		
	Total	36.300	127			
10	Regression	27.532	10	2.753	36.739	.000[j]
	Residual	8.768	117	.075		
	Total	36.300	127			
11	Regression	27.889	11	2.535	34.967	.000[k]
	Residual	8.411	116	.073		
	Total	36.300	127			

Table 5.39 Stepwise regression coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	Constant	8.314	.131		63.270	.000	8.054	8.574
	Q17	.323	.039	.596	8.336	.000	.246	.399
2	Constant	7.649	.147		51.991	.000	7.358	7.940
	Q17	.254	.034	.469	7.365	.000	.185	.322
	Q7	.278	.040	.443	6.969	.000	.199	.357
3	Constant	7.365	.150		49.189	.000	7.069	7.662
	Q17	.215	.033	.398	6.521	.000	.150	.281
	Q7	.228	.039	.363	5.895	.000	.151	.304
	Q6	.172	.037	.288	4.609	.000	.098	.245
4	Constant	7.183	.147		48.745	.000	6.892	7.475
	Q17	.167	.033	.309	5.058	.000	.102	.233
	Q7	.216	.036	.344	5.924	.000	.144	.288
	Q6	.154	.035	.258	4.362	.000	.084	.224
	Q12	.134	.032	.247	4.166	.000	.070	.197
5	Constant	6.971	.155		44.942	.000	6.663	7.278
	Q17	.157	.032	.291	4.926	.000	.094	.220
	Q7	.202	.035	.323	5.747	.000	.133	.272
	Q6	.144	.034	.242	4.245	.000	.077	.212
	Q12	.135	.031	.249	4.367	.000	.074	.196
	Q15	.106	.032	.176	3.357	.001	.044	.169
6	Constant	7.081	.155		45.637	.000	6.774	7.388
	Q17	.152	.031	.282	4.915	.000	.091	.214
	Q7	.216	.035	.344	6.266	.000	.148	.285
	Q6	.153	.033	.257	4.623	.000	.088	.219
	Q12	.135	.030	.249	4.507	.000	.076	.194
	Q15	.128	.032	.213	4.061	.000	.066	.191
	Q16	-.082	.028	-.154	-2.930	.004	-.137	-.027
7	Constant	6.975	.156		44.709	.000	6.666	7.283
	Q17	.140	.031	.258	4.567	.000	.079	.200
	Q7	.230	.034	.366	6.761	.000	.162	.297
	Q6	.142	.032	.238	4.377	.000	.078	.207
	Q12	.117	.030	.215	3.894	.000	.057	.176
	Q15	.118	.031	.195	3.788	.000	.056	.179
	Q16	-.088	.027	-.165	-3.214	.002	-.142	-.034
	Q14	.080	.029	.146	2.754	.007	.023	.138
8	Constant	7.106	.161		44.055	.000	6.786	7.425
	Q17	.141	.030	.261	4.726	.000	.082	.201
	Q7	.228	.033	.363	6.864	.000	.162	.294
	Q6	.152	.032	.254	4.738	.000	.088	.215
	Q12	.127	.030	.235	4.305	.000	.069	.186

Table 5.39 Stepwise regression coefficients (cont.)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
	Q15	.120	.030	.199	3.945	.000	.060	.180
	Q16	-.082	.027	-.153	-3.047	.003	-.135	-.029
	Q14	.091	.029	.166	3.156	.002	.034	.148
	Q18	-.078	.031	-.127	-2.516	.013	-.139	-.017
9	Constant	7.054	.159		44.363	.000	6.739	7.369
	Q17	.141	.029	.260	4.814	.000	.083	.199
	Q7	.222	.033	.353	6.797	.000	.157	.286
	Q6	.156	.031	.262	4.983	.000	.094	.218
	Q12	.118	.029	.217	4.024	.000	.060	.175
	Q15	.100	.031	.166	3.267	.001	.039	.161
	Q16	-.082	.026	-.154	-3.125	.002	-.134	-.030
	Q14	.082	.028	.150	2.905	.004	.026	.139
	Q18	-.089	.030	-.146	-2.925	.004	-.150	-.029
	Q9	.076	.030	.130	2.538	.012	.017	.136
10	Constant	7.112	.159		44.806	.000	6.797	7.426
	Q17	.142	.029	.262	4.920	.000	.085	.199
	Q7	.230	.032	.367	7.124	.000	.166	.294
	Q6	.173	.032	.289	5.434	.000	.110	.236
	Q12	.128	.029	.236	4.390	.000	.070	.186
	Q15	.105	.030	.174	3.460	.001	.045	.165
	Q16	-.076	.026	-.144	-2.953	.004	-.128	-.025
	Q14	.094	.028	.171	3.300	.001	.037	.150
	Q18	-.091	.030	-.149	-3.034	.003	-.151	-.032
	Q9	.073	.030	.124	2.471	.015	.015	.132
	Q5	-.068	.031	-.115	-2.185	.031	-.129	-.006
11	Constant	7.078	.157		45.117	.000	6.767	7.388
	Q17	.133	.029	.245	4.641	.000	.076	.189
	Q7	.229	.032	.365	7.209	.000	.166	.292
	Q6	.166	.031	.278	5.282	.000	.104	.228
	Q12	.122	.029	.225	4.225	.000	.065	.179
	Q15	.107	.030	.177	3.587	.000	.048	.166
	Q16	-.083	.026	-.156	-3.238	.002	-.134	-.032
	Q14	.076	.029	.138	2.607	.010	.018	.133
	Q18	-.094	.030	-.155	-3.189	.002	-.153	-.036
	Q9	.071	.029	.121	2.437	.016	.013	.129
	Q5	-.074	.031	-.125	-2.408	.018	-.135	-.013
	Q8	.071	.032	.117	2.219	.028	.008	.134

a. Dependent Variable: Y

Table 5.40 Residuals statistics of stepwise analysis

	Min	Max	Mean	Std. Deviation	N
Predicted Value	7.9965	10.4464	9.3625	.46861	128
Std. Predicted Value	-2.915	2.313	.000	1.000	128
Standard Error of Predicted Value	.039	.120	.081	.017	128
Adjusted Predicted Value	7.8382	10.5053	9.3598	.47544	128
Residual	-.68034	.70002	.00000	.25735	128
Std. Residual	-2.527	2.600	.000	.956	128
Stud. Residual	-2.629	2.884	.005	1.008	128
Deleted Residual	-.73642	.86177	.00270	.28691	128
Stud. Deleted Residual	-2.699	2.981	.006	1.017	128
Mahal. Distance	1.733	24.213	10.914	4.814	128
Cook's Distance	.000	.160	.010	.019	128
Centered Leverage Value	.014	.191	.086	.038	128

a. Dependent Variable: Y

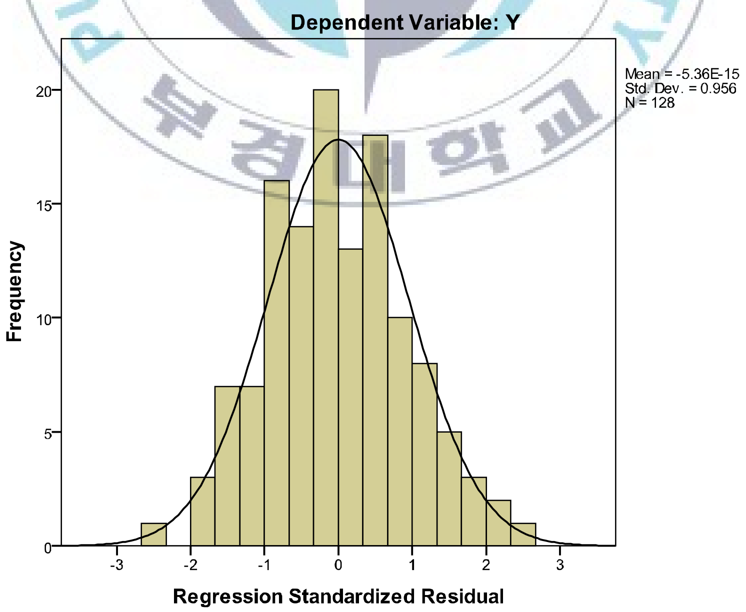


Figure 5.11 Histogram of stepwise analysis

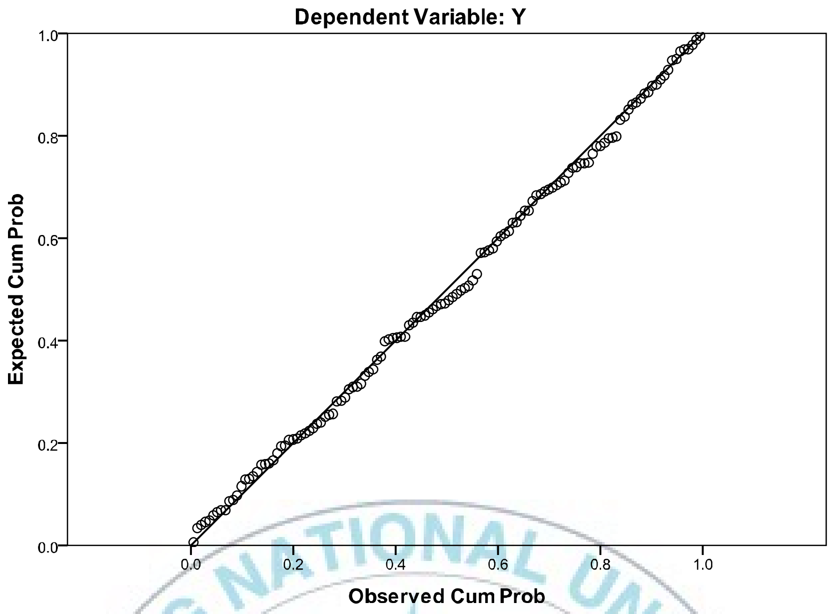


Figure 5.12 Normal P-P plot of stepwise regression standardized residual

5.3.9.2 By artificial neural network

Artificial neural network (ANN) was also used to develop a model to predict the effect of waste factors on project performance cost. The results of prediction from ANN model will be compared to the results from LR model. In ANN, 80% of the total number of data has been used for training neural network whereas remaining 20% has been used for testing. Number of epochs used are 1000 at which network shows maximum convergence. Learning algorithm used is gradient decent with momentum back propagation with log tangent transfer function. Learning rate and momentum factor used in the model is 0.4 and 0.9. The optimization algorithm employed is *scaled conjugate gradient*. The activation functions are *hyperbolic tangent* in hidden layer and *sigmoid* in output layer. Figure 5.13 illustrates the summary of ANN prediction model. The *t*-test analysis is then used to find out the difference between observed and predicted mean value. The Mean Absolute

Percentage Error (MAPE) and R^2 index are adopted to measure the prediction accuracy of the model.

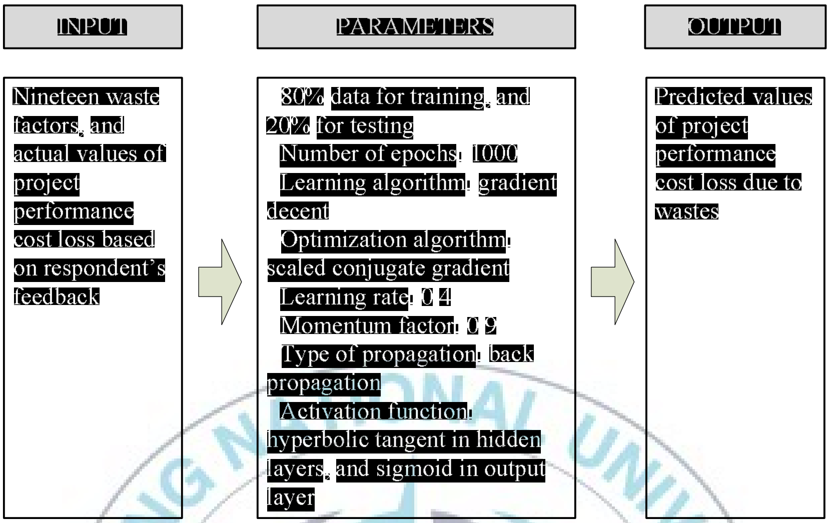


Figure 5.13 Summary of ANN prediction model

The result of factor analysis has shown that only 56.7% of variance is accounted for the waste factors in construction projects in five extracted factors. As the rule of thumb, explained variance larger than 80% is the cut-off criteria. Therefore, this result cannot be utilized in the prospective analysis. It means that all variables mentioned in Table 3.2 must be simultaneously considered.

The configuration of the model is four-layer back propagation network. The input layer has nineteen neurons representing the nineteen waste factors (X_i) of construction projects. The output layer has one neuron representing the percentage of increased project cost due to these wastes (Y). In order to develop the hidden layer, Ripley (1996) stated that the model with two hidden layers can approximate any mapping with highest accuracy. Furthermore, Liu (1998) proposed that the number of neurons in each hidden layer can be estimated in range from ($2\sqrt{n} + m$) to (2n + 1). In these formulas, n is the number of input neurons and m is the number of output neurons. Thus, the model has two hidden layers with fifteen neurons (H_i) in each as shown in Figure 5.14. The results of prediction by ANN are shown in Appendix 2, as well as by LR model.

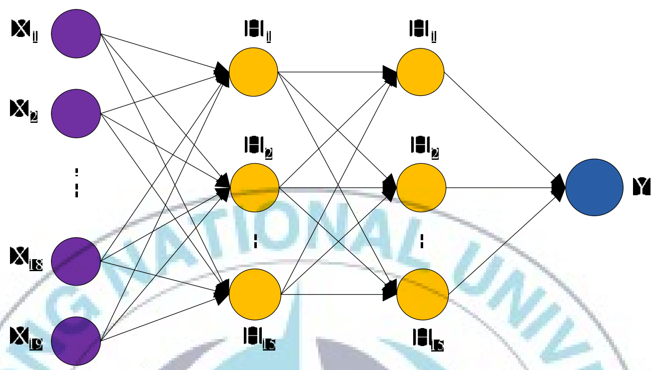


Figure 5.14 Configuration of artificial neural network

Table 5.41 presents the ANN model summary. The sum of squares error is 0.156 and the relative error is 0.067 for training data sets. Figure 5.15 shows the scatter plot of the actual values against the predicted values. It is easily observed that the distribution of points is approximately along the straight line in the plot.

Table 5.41 ANN model summary

Training	Sum of Squares Error	.156
	Relative Error	.067
	Stopping Rule Used	1 consecutive step(s) with no decrease in error[a]
	Training Time	00:00:00.091
Testing	Sum of Squares Error	.115
	Relative Error	.171

Dependent Variable: Y

a. Error computations are based on the testing sample.

Figure 5.16 shows the scatter plot of the residuals against the predicted values. It is clear that there is no relationship between residuals and predicted values because the residuals are randomly distributed in a band clustered around the horizontal line through value of 0, the assumptions of linearity and homogeneity of variance are met.

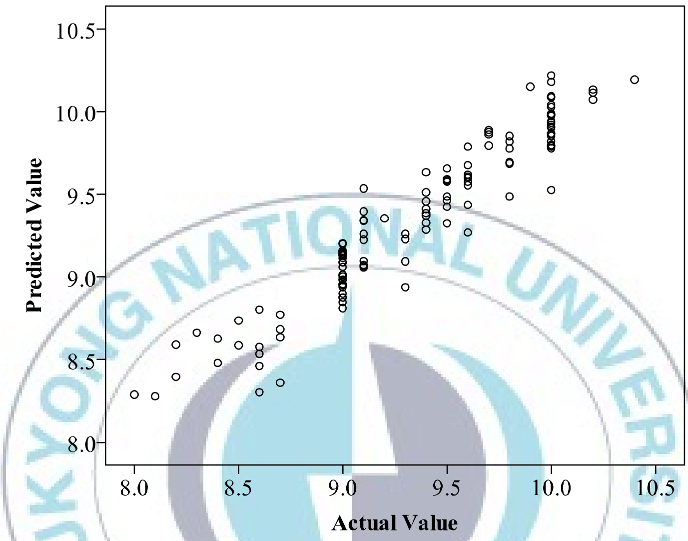


Figure 5.15 Plot of actual values against predicted values

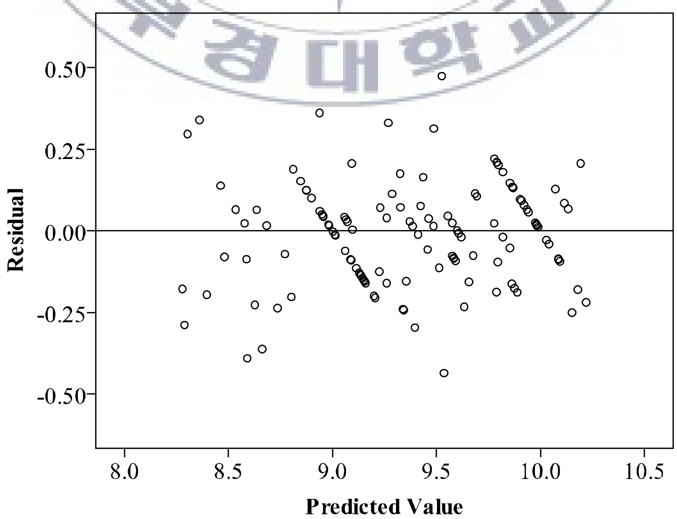


Figure 5.16 Plot of residuals against predicted values

Table 5.42 Independent variable importance

#	Importance	Normalized Importance
Q1	.052	43.9%
Q2	.037	30.7%
Q3	.036	29.7%
Q4	.042	35.0%
Q5	.038	31.5%
Q6	.110	92.1%
Q7	.120	100%
Q8	.064	53.6%
Q9	.055	46.1%
Q10	.020	17.0%
Q11	.026	21.7%
Q12	.080	67.1%
Q13	.030	24.8%
Q14	.036	30.0%
Q15	.059	49.3%
Q16	.058	48.9%
Q17	.058	48.5%
Q18	.045	37.9%
Q19	.033	27.9%

Table 5.42 shows the importance levels of independent variables in predicting the results of ANN model. The importance levels are then normalized in the scale of 100. The results are shown in Figure 5.17.

Percentage errors (PE) are plotted in Figure 5.18 (calculated based on Eq. (3.8)). The minimum and maximum are -4.70% and 4.84% respectively, that fall well into the acceptable limit of 10% (Chan and Chan, 2004). Furthermore, MAPE value is 1.35%, and R-squared index is 0.911 as shown in Table 5.45 (calculated based on Eq. (3.9), and (3.10)). These show that the model can explain 91.1% of variance of increased project cost.

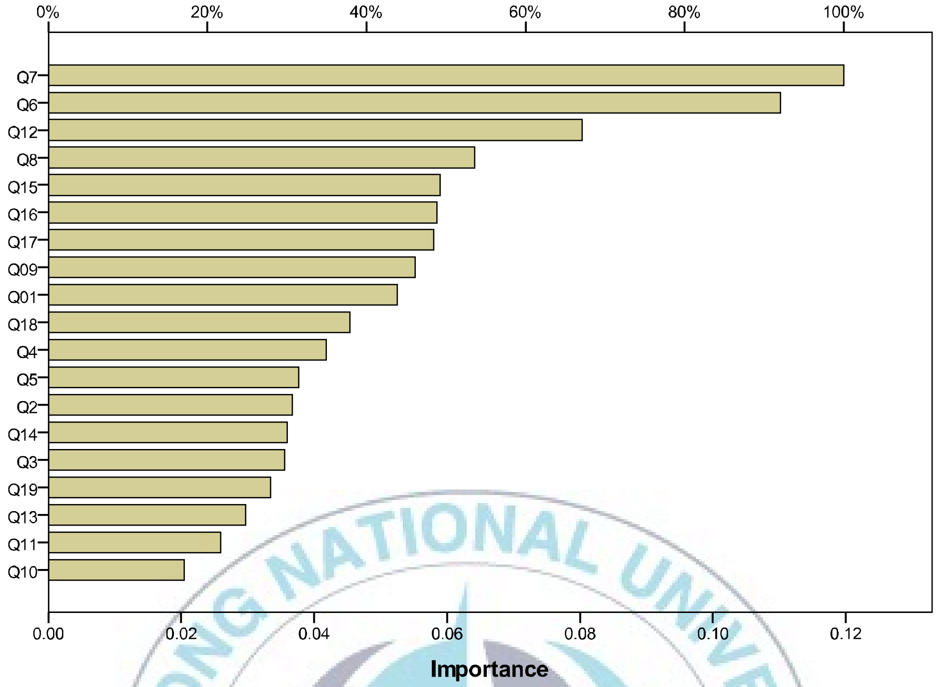


Figure 5.17 Normalized importance

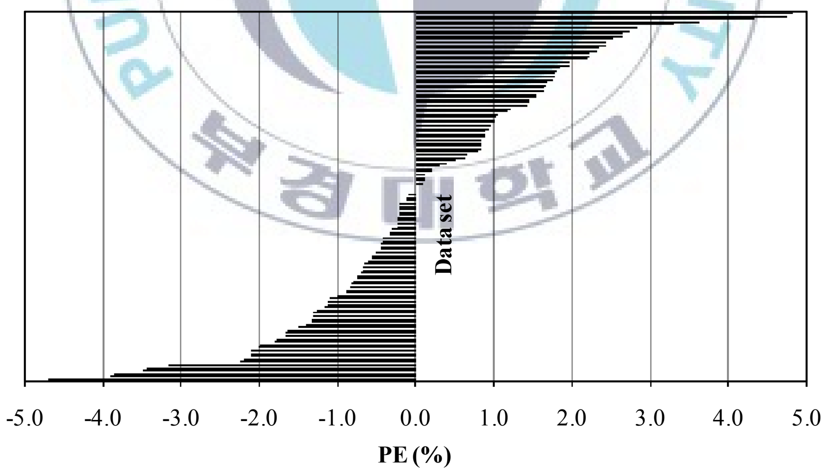


Figure 5.18 Observed chart of percentage errors

Moreover, *t*-test analysis between observed and predicted mean value will be performed. The results of one-sample statistics are shown in Table 5.43, and the results of one-sample test are shown in Table 5.44.

Table 5.43 One-sample statistics

	N	Mean	Std. Deviation	Std. Error Mean
Actual value	128	9.3625	.53463	.04725
Predicted value	128	9.3728	.49911	.04412

Table 5.44 One-sample test

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean	95% Confidence Interval	
					Lower	Upper
Actual value	198.128	127	.000	9.3625	9.2690	9.4560
Predicted value	212.461	127	.000	9.3728	9.2855	9.4601

Based on Eq. (3.3), (3.4), and (3.5), the p-value can be found from t-value as following calculation:

$$SE = \sqrt{\frac{\sigma_p^2}{n_p^2} + \frac{\sigma_a^2}{n_a^2}} = \sqrt{\frac{0.53^2}{128^2} + \frac{0.50^2}{128^2}} = 0.0055$$

$$t = \frac{\mu_p - \mu_a}{SE} = \frac{(9.3625 - 9.3728) - 0}{0.0055} = 1.873$$

$$df = (n_p - 1) + (n_a - 1) = (128 - 1) + (128 - 1) = 254$$

At the df of 254, t = 1.873 lies between the critical values for p = 0.10 ($t_{0.10}$ = 1.969) and p = 0.05 ($t_{0.05}$ = 1.651). By interpolating between these values, the p-value could be defined as 0.085.

Evidence from the *t*-test (see Table 5.45), the difference between these mean values is not significant because the p-value is 0.085 greater than 0.05.

Thus, the predicted values of ANN model do not diverge significantly from the observed values.

Table 5.45 Accuracy assessment of the ANN model

Mean increased project cost with 95% confidence interval		T-test		MAPE (%)	R-squared (%)
Observed (%)	Predicted (%)	P-value	Significant?		
9.3625	9.3728	0.085	Not significant	1.350	0.911

5.3.10 Identification of main wastes by elasticity test

Venkataraman *et al.* (1995) suggested that elasticity test could be done by perturbing each of the input variables, one at a time, by 5% change. However, in this study, all input variables were asked by a five-point Likert scale. Thus, this study has proposed that the process of elasticity test was performed by adding one to each input variable for each time of data run as a loop from one to five. Each time, the model is restrained and the elasticities are computed for the remaining input variables. This could be done because of the highly non-linear relationships existing in the ANN model (Zhao and Chua 2003). The results of calculation based on Eq. (3.11) are shown in Table 5.46. For example, perturb each collected data set of input variable X_1 by a loop from one to five, the maximum elasticity of the output is 0.08%.

The results indicate that the first five factors that has most impact on total project cost have the contribution of both direct conversion wastes, non-contributory time wastes, and contributory time wastes. Among them, Q17 *'time for supervising and inspecting the construction works'* is the first ranked factor with 0.59%. Some reasons that can be explained for this finding are that poor coordination among project participants, too few supervisors, inexperience inspectors, etc. Q10 *'Waiting for others to complete their works before the proceeding works can be carried out'* is the next factor in the ranking table with 0.33%. Inappropriate construction methods and outdated equipment are the problems that frequently happen in Vietnam construction industry. These make workers cannot complete their work on schedule; therefore, the planned works often are blocked.

The third rank is Q9 *'accidents on site'* with 0.26%. Because the construction industry in Vietnam just developed, the professionals have not paid much attention to the accident problems on site. There is even no methodical Health–Safety–Environment (HSE) program applied in a construction project. Therefore, accidents on site can happen in any circumstance under any cause both direct and indirect cause. This can lead to the loss of project cost and time during construction period. Q19 *'Time for transporting workers, equipment and materials'* is the fourth ranked waste factor with 0.25%. Poor site layout and inadequate worker distribution are considered as the most causes for this problem. Q16 *'Time for workers' rest during construction'* and Q5 *'material lost/ stolen from site during construction period'* are ranked as the fifth waste factor with 0.14%. As the work is planned irrationally, workers may take much time to rest during working time. Materials on sites were stolen and lost due to poor storage and weakness of security system in construction site (Khanh, 2011).

Q11 *'waiting for equipment to be delivered on site'*, X2 *'over-allocated/ unnecessary materials on site'*, Q18 *'time for instructions and communication between engineers and workers'*, and Q14 *'waiting for the clarification and confirmation by client and consultants'* are the next ranked factors with the mean value greater than 0.1%. The reasons for these problems are not only as mentioned above, but also lack of working skills, bureaucracy, lack of appropriate control, poor site documentation, poor material delivery schedule, defective design, etc. Remaining waste factors can be neglected due to their mean value is lower than 0.1%.

Table 5.46 Results of elasticity test

#	Waste factors	Max E_k (%)	Rank
Q17	Time for supervising and inspecting the construction works	0.59	1
Q10	Waiting for others to complete their works before the proceeding works can be carried out	0.33	2
Q9	Accidents on site	0.26	3
Q19	Time for transporting workers, equipment and materials	0.25	4
Q16	Time for workers' rest during construction	0.14	5
Q5	Material lost/ stolen from site during construction period	0.14	5
Q11	Waiting for equipment to be delivered on site	0.13	6
Q2	Over-allocated/ unnecessary materials on site	0.12	7
Q18	Time for instructions and communication between engineers and workers	0.11	8
Q14	Waiting for the clarification and confirmation by client and consultants	0.11	8
Q7	Mishandling or error in construction applications/ installations	0.09	9
Q13	Waiting for skilled workers to be provided on site	0.08	10
Q1	Over-allocated/ unnecessary equipment on site	0.08	10
Q12	Waiting for materials to be delivered on site	0.07	11
Q4	Unnecessary procedures and working protocols	0.04	12
Q8	Materials for reworks/ repaired works/ defective works	0.03	13
Q6	Material deteriorated/ damaged during construction period	0.03	13
Q15	Time for reworks/ repaired works/ defective works	0.03	13
Q3	Over-allocated/ unnecessary workers on site	0.01	14

5.4 Comparison between selected countries

The objective of this section is to get a general view about the waste factors that have most effect on project performance among developing countries and some developed countries through an examination of five major factors from this survey and five different selected previous studies. The selected studies are up-to-date or have been done in past nearly 10 years. Although these studies are not definitely similar about the purpose and method of survey, the comparison is useful for understanding the problems of cost loss of construction projects due to waste problems in developing countries as shown in Table 5.47.

Time for supervising and inspecting the construction works is the most severe in Vietnam (rank 1). It is mainly related to the coordination between participants in the project. It also appears in Indian construction industry (rank 2). The waste factor related to labor problem mostly occurs in all selected countries, i.e., time for worker's resting during construction in Vietnam (rank 5), labor slowness or effectiveness in Indonesia (rank 4), labor inefficiency in Singapore (rank 1), waiting due to crews interference in India (rank 1), and waste due to untrained labor in Egypt (rank 5). It is mainly due to poor personnel plan during construction period.

The next frequently common waste factor is related to equipment and material problems, i.e., time for transporting workers, equipment and materials in Vietnam (rank 4); waiting for materials and waste of raw materials on site in Indonesia (rank 2 and 5); equipment inefficiency, material scrap and excess inventory of materials in Singapore (rank 2, 3 and 4), and equipment used by other crew and waiting due to equipment's installation in India (rank 3 and 4). This finding indicates that why material waste has been studied much in the past. Similar to other countries, material waste always contribute a large proportion to total amount of construction waste in Vietnam. Eventually, rework is the last common waste problem between Korea (rank 1), Indonesia (rank 1) and Singapore (rank 5). This waste is usually derived from defective design, inexperienced people and outdated equipment. Remaining waste factors belong to each country individually.

Table 5.47 Comparison between selected countries

Country	Major wastes				
	1	2	3	4	5
Vietnam (This study, 2012) (1)	Time for supervising and inspecting the works	Waiting for others to complete their works	Accidents on site	Time for transporting workers, equipment and materials	Time for workers' resting during construction
Indonesia (Alwi *et al.*, 2002) (2)	Repair on finishing works	Waiting for materials	Delays to schedule	Labor slowness or ineffectiveness	Waste of raw material on site
Singapore (Zhao and Chua, 2003) (2)	Labor inefficiency	Equipment inefficiency	Material scrap	Excess inventory of materials	Rework
India (Ramaswamy and Kalidindi, 2009) (1)	Waiting due to crews interference	Waiting due to inspection	Equipment used by other crew	Waiting due to equipment's installation	Waiting for instruction
Egypt (Garas *et al.*, 2001) (2)	Waste due to late information	Waste due to uncompleted design	Waste due to poor control	Waste due to unnecessary people moves	Waste due to untrained labor
Korea (Lee *et al.*, 2007) (1)	Rework	Overlapping work	Inaccurate orders and accounts	Estimation differences between the field and office	Delay in decision-making

Note: (1): project cost or time; (2): other project aspects

5.5 Discussion

In general, this study showed that waste problems have significant impact on project efficiency mainly due to lack of perception about concepts of waste. Project managers do not know clearly about what the principles of LC are, but they have been trying to find better methods to perform the project with minimum possible level of waste. Therefore, it is recommended that the construction industry should pay much attention in training employees and practitioners on the new concepts of waste in LC in order to reduce the share of value loss in future projects (Khanh, 2011).

There is also a problem with using the term "waste" because it does not give an accurate description of the cost reduction potential. First of all, there can be cost reductions by rendering the value adding tasks more efficient. Secondly, there are costs that do not add any direct value, but which indirect value can be significant, e.g., some managerial tasks and non-value adding activities that result in increased knowledge. Thirdly, the focus on costs is one-side. A total economic analysis should as well consider the revenues and the costs for alternative solutions in order to know what actions to take (Forberg and Saukkoriipi, 2007).

It is mostly no meaning to conduct complete measurements in every construction project since this would cost too much and thus increase the amount of waste. However, this does not mean that there never should be any measurements. Measuring waste leads to facts that can be used when a company, an industry or the entire society decides how to render activities more effective. Without this kind of facts, it is difficult to know what measures to take. Thus, it is important that some measurements are performed. In addition, it can be valuable to think about which activities are wasteful without actually doing any detailed studies. Only considering about activities in terms of value and non-value adding could be helpful when trying to achieve cost reductions (Forberg and Saukkoriipi, 2007).

The level of wastes varies on each project according to its design and construction characteristics. Thus, practitioners should estimate their own level suited with distinct projects before construction. Previous studies have shown that level of wastes in construction projects will be reduced if their causes are prevented. Future studies should be conducted to examine the sources causing the waste happened in the sites especially in the sources found in this study. Moreover, case studies about relationship between particular causes and wastes should be performed to assess the current status of waste level more detailed. The strategies to reduce the effect of waste can be then drawn based on their causes.

By taking care of the main causes of waste in present and future projects, construction managers can control waste in their performance processes. Therefore, a construction project can be achieved more success if all employees know how to control completely the wastes in every activity on their site. Since then, the profit of project may increase through reducing or eliminating the wastes.

5.6 Summary

By administering and analyzing a questionnaire survey, this study has identified problems related to the wastes and their causes in construction projects based on the principles of LC. Nineteen waste factors and twenty-three causes of waste were identified based on previous studies. The major objective of this study is to examine the current perspective of waste problems in construction projects as well as the main cause for these wastes. The main results of the study are as follows:

- The perception and experience of the employees about waste concepts are the basis of this study. The results showed that the recognition about waste and its control ability are quite high, but the relationship between them is quite low with 0.461, 0.695 and 0.701 respectively for contributory time waste, direct conversion waste, and non-contributory time waste whether or not that waste is controlled.

- Nine hypotheses about inter-relationship between recognition, control ability, and frequency of waste for three waste groups are tested by Pearson correlation analysis. The results showed that most of them are non-significant relationship. Only one case has negative relationship ($r = -0.236$) between recognition and frequency of the contributory time wastes.

- Based on the ranking of frequency of occurrences, the top waste factors belong to the direct conversion waste group. These wastes are Q5 & Q6 'material lost or deteriorated from site during construction periods', and Q18 'time for instructions and communication between engineers and workers. The main causes belong to the management/ administration cause group. These causes are A3 'lack of control', A2 'poor planning and scheduling', and A4 'bureaucracy'. Eventually, based on the cause-and-effect analysis, the most likely cause for all wastes is the people cause with 52.6%, and the most unlikely cause is the information/ communication cause with 0%.

- From factor analysis results, five factors are extracted with 56.7% of variance explained for the waste factors in construction projects. Component 1 (PC1), namely "Resource Plan and Storage", can explain for seven variables involving Q10, Q11, Q6, Q5, Q12, Q4 and Q17. Component 2 (PC2), namely "Resource Distribution and Usage", is for four variables involving Q2, Q3, Q1, and Q7. Component 3 (PC3), namely Working Procedure", is for two variables involving Q13 and Q18. Component 4 (PC4), namely "Communication and Transport", is also for two variables involving Q14 and Q9 . Finally, component 5 (PC5), namely "Workers' Rest", is for one variable, i.e., Q16. Based on these five components, the WOLI is found as 61.55% in the scale of 0-100%. It indicates that level of waste in VCI is fairly high.

- The mean value of project cost loss due to the waste factors is approximately 9.36% of total cost. The results of estimating the effect of waste factors on project performance cost by ANN model shows that the difference between predicted value and actual value is quite small. In detail, the MAPE is only 1.35%, and R-squared index is 0.911. Whereas, LR model produces a results with a lower degree of accuracy with R-squared is only 78.9%.

- Elasticity test shows that the five most important waste factors are Q17 'time for supervising and inspecting the construction works' with elasticity of 0.59%, Q10 'waiting for others to complete their works before the proceeding works can be carried out' (0.33%), Q9 'accidents on site' (0.26%), Q19 'time for transporting workers, equipment and materials' (0.25%), and Q16 'time for workers' rest during construction' (0.14%).

Wastes are harmful to project value; therefore, finding solutions to prevent or reduce them is necessary and urgent. Under the philosophies of LC, concepts of waste are not restricted in wastes related to materials and equipment. This chapter has presented the perception of professionals about new waste concepts in the construction industry. The frequencies of waste occurrence and their causes have been also examined. The main causes for waste factors have been found based on their causal relationship. The effect of wastes on project efficiency has been predicted based on ANN. The most effective waste factors have been then identified based on elasticity test. In summary, there is a significant level of wastes existing in the VCI under the new philosophies and principles of LC.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This research was to examine the waste problems in Vietnam construction industry through questionnaire survey and experts survey. Prior to explore these waste problems, the current practical characteristics in manufacturing and construction are studied first. This research was conducted based on the new philosophies and tools, which lead to lean production in construction. They include new concepts of waste that were originated from Toyota lean production system. Discussion for every analysis result was properly presented to understand the current situation of Vietnam construction industry especially in waste problems. In general, one of the most impacted factors causing waste occurrence identified in this study is poor production planning and control.

In the beginning, the lean philosophies and tools in manufacturing production were briefly introduced in this study. The potential of implementing these philosophies and tools in practical construction production (called "Lean Construction") was investigated and reported based on previous studies. The waste concepts and its classification were then explored and filtered from these studies. The perception of professionals in the construction industry about each waste factor was examined through its recognition ability, control ability and frequency of occurrence. The recommendations for each investigated case were proposed based on its causes of waste. It is easily seen that wastes are the unnecessary item in production but the perception of professionals in the industry on these wastes is quite low. Implementing the principles and tools of LC in the practice creates a great opportunity to reduce existing wastes, enhance efficiency of processes, and generate maximum possible value of project. Therefore, practitioners should increase their perception on waste problems when performing a construction project.

Wastes have caused a considerable loss for project values under customer's viewpoint. In the past, wastes were only considered as physical losses related to materials. Currently, the concepts of waste in LC are broadened to the items related to time for waiting, inspection, transportation, etc. These wastes are mainly derived from the weak management for flow activities (resource and information flows). Unfortunately, the professionals in the construction industry often tend to accept a reasonable share of these wastes in the total loss of project value rather than try to find solutions for preventing or reducing them. Therefore, practitioners could adopt the findings of this research to improve their knowledge about waste, as well as make corrective actions for the current issues on their sites.

The new concepts of waste and its control ability were perceived quite high by professionals in the construction industry. However, the relationship strength between waste recognition and its control ability is quite weak for all three surveyed waste groups (direct conversion waste group, non-contributory time waste group, and contributory time waste group). It means that waste is recognized but it may not be controlled in practice, and vice versa. Furthermore, the Pearson correlation analysis showed that there are non-significant relationship between recognition, control ability, and frequency of occurrences for all three waste groups above. This indicates that waste is a very complicated item in construction projects.

According to the rankings of occurrence frequency, the three top waste factors belong to direct conversion waste group, i.e., ‘material lost or stolen from the site during construction periods’, ‘material deteriorated or damaged during construction periods’, and ‘time for instructions and communication between engineers and workers. And, the three top causes of waste belong to management cause group, i.e., ‘lack of control’, ‘poor planning and scheduling’, and ‘bureaucracy’. However, based on cause-and-effect analysis, the people-related causes group is the most dominant group for the waste factors.

Through employing factor analysis to see the latent relationship between the waste factors, only five factors are extracted with 56.7% of variance that can explain for nineteen initial factors. They are ‘resource distribution and storage’, ‘resource distribution and usage’, ‘working procedure’, and ‘workers’ rest’. Based on these five components, the WOLI was found as 61.55 in the scale of 100. It shows that the level of waste in the construction industry in Vietnam is fairly high.

Unfortunately, as a rule of thumb, because the variance of five principal components that explains for nineteen initial waste factors is 56.7% less than 80%, the results from factor analysis could not be utilized for further analyses. In order to predict the effect of waste factors to total project performance cost, the LR and ANN model were employed. The results of prediction showed that the mean value of loss is about 9.36% of total project cost. The degree of accuracy of the ANN model is higher than LR model, which shows the MAPE of 1.35% and R^2 of 91.1%.

The results of elasticity test showed that the five top waste factors that have the strongest impact on the project cost are ‘time for supervising and inspecting the construction works’, ‘waiting for others to complete their works before the proceeding works can be carried out’, ‘accidents on site’, ‘time for transporting workers, equipment and materials’, and ‘time for workers’ resting during construction’. However, all of them are related to wastes of time that are low recognized by the professionals. Therefore, it is suggested that the construction industry should pay much more attention to the training and education tasks for both managers and personnel.

6.2 Limitations

Because of the difficulties in long geographical distance between the researcher’s place and the survey’s place, this study has met several certain limitations as follows:

- First, most of surveys are based on respondents’ experience. The non-probability sampling method is employed because many of respondents are acquainted with the researcher. Furthermore, the sample size is restricted to a little number of responses that impossibly represent the entire population of the construction industry in Vietnam. Moreover, the area of study is limited only in Ho Chi Minh city – the biggest city in Vietnam.

- Second, this study has not examined the issues related to the perception of parties (owner, consultant, and contractor) in construction projects. Each project party has each different role in project. Thus, the role of practitioners in a project will affect their perceptions about implementation of lean thinking.

- Third, the scope and type of project that requires different project financing and construction method has not been concerned as well. For example, building project has different characteristics about cost, time, quality with bridge project.

- Fourth, this study has only considered the problems related to wastes and production planning; thus, it does not reflect the whole lean thinking in the construction industry. Furthermore, the philosophies and tools of LC are still very new categories for the construction industry.

6.3 Future studies

Prospective studies could focus on overcoming the limitations above through some suggestions as follows:

- Use the probability sampling method when collecting data with a sample size representing the survey population.
- Examine the perceptions of different project parties such as owners, consultants, and contractors about the problems leading to lean thinking in current practice.
- Examine the lean thinking in each project type such as building, bridge, harbor, tunnel, damn, etc.
- Investigate other aspects of lean thinking to find out its current perspective in the construction industry.
- Build an effective communication model between engineers and workers, and between parties involved in a project to prevent the waste occurrences.

In addition, based on the findings of this research, prospective studies can be conducted to develop waste models, and measurement methods for wastes especially waste of time, and detailed role of each production planning process in controlling the waste occurrence. Other related matters such as elimination or prevention solutions for causes of existing wastes, role of communication and trust between parties, and strategy for implementation of production planning and control system should be focused as well.

6.4 Recommendations

Similar to developing countries, the construction industry in Vietnam is facing with a lot of wastes during construction. Many of them were left unnoticed or unattended. Nowadays, in the period of integration and development to the international market, the demand of improving the construction efficiency is very large. In this context, waste has been long considered as a item that needs to be eliminated or reduced as much as possible. In last decades, LC has been considered as a way to design production system to minimize wastes. The philosophies and tools of LC have been derived from lean production in manufacturing. In order to use LC philosophies and tools to reduce or eliminate wastes in Vietnam, as well as other developing countries, there are some recommendations:

- As mentioned early, wastes are mainly considered as a source of value loss related to materials. Under LC philosophies, especially in philosophies of managing flow activities, wastes are also related to time and efforts for completing the products. Thus, practitioners themselves should enhance their perception about new waste concepts.

- Arranging team seminars or workshop to present the LC philosophies and tools for all employees, especially people who are in-charging the role of top management. Furthermore, the periodic training and education program for applying LC tools in practice should be included.
- Making a “learning cycle” through analyzing the failure reasons for the uncompleted works in weekly team meetings. In construction projects, learning from the past is one of the best ways to improve the improvement strategies. It leads to efficiency increase in prospective projects.
- The construction industry should conduct a “First Run Study” (FRS) for implementation of LC philosophies and tools. Because LC has been proposed from some developed countries, the particularities between them should be inspected first.

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APPENDIX

APPENDIX 1

QUESTIONNAIRE

A Study on Waste Problems in Vietnam Construction Industry Based on Lean Philosophies

Dear **Sir/ Madam,**

Lean Construction (LC) is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value. Under the principles of LC, concepts of wastes (or non value-adding activities) are defined as "*any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building*".

The main purpose of this research is to examine the current practice of waste recognition and control in Vietnam construction industry, and study the effect of the waste problems on project performance efficiency.

I will highly appreciate your experience, and always listen your opinions and ideas. I hope that this study, with the enthusiastic participation from you, will contribute to the development of the construction industry. I assure that your responses will be confidentially kept, and will be only published as the general attitudes of the survey. The questionnaire takes about 15-20 minutes to be completed.

Thank you very much.

Ha Duy Khanh

PART 1: Waste Recognition and Control

According to your experience, which are the following items or activities can be best represented or described as "waste" and whether or not it is controlled? (Please mark "X" to the cell for your answer).

#	Waste factors	Recognition		Control	
		Yes	No	Yes	No
Q1.1	Over-allocated/ unnecessary equipment on site				
Q1.2	Over-allocated/ unnecessary materials on site				
Q1.3	Over-allocated/ unnecessary workers on site				
Q1.4	Unnecessary procedures and working protocols				
Q1.5	Material lost/ stolen from site during construction period				
Q1.6	Material deteriorated/ damaged during construction period				
Q1.7	Mishandling or errors in construction applications/ installations				
Q1.8	Materials for reworks/ repaired works/ defective works				
Q1.9	Accidents on site				
Q1.10	Waiting for others to complete their works before the proceeding works can be carried out				
Q1.11	Waiting for equipment to be delivered on site				
Q1.12	Waiting for materials to be delivered on site				
Q1.13	Waiting for skilled workers to be provided on site				
Q1.14	Waiting for the clarification and confirmation by client and consultants				
Q1.15	Time for reworks/ repaired works/ defective works				
Q1.16	Time for workers' rest during construction				
Q1.17	Time for supervising and inspecting the construction works				
Q1.18	Time for instructions and communication between engineers and workers				
Q1.19	Time for transporting workers, equipment and materials				

PART 2: Waste Occurrence and Its Impact

According to your experience, what is the frequency of occurrence of the mentioned activities on construction sites? Please circle the number following scale below:

“1” = “Never”, “2” = “Seldom”, “3” = “Sometimes”,

“4” = “Frequently”, “5” = “Very frequently”

#	Waste factors	Answer				
Q2.1	Over-allocated/ unnecessary equipment on site	1	2	3	4	5
Q2.2	Over-allocated/ unnecessary materials on site	1	2	3	4	5
Q2.3	Over-allocated/ unnecessary workers on site	1	2	3	4	5
Q2.4	Unnecessary procedures and working protocols	1	2	3	4	5
Q2.5	Material lost/ stolen from site during construction period	1	2	3	4	5
Q2.6	Material deteriorated/ damaged during construction period	1	2	3	4	5
Q2.7	Mishandling or error in construction applications/ installations	1	2	3	4	5
Q2.8	Materials for reworks/ repaired works/ defective works	1	2	3	4	5
Q2.9	Accidents on site	1	2	3	4	5
Q2.10	Waiting for others to complete their works before the proceeding works can be carried out	1	2	3	4	5
Q2.11	Waiting for equipment to be delivered on site	1	2	3	4	5
Q2.12	Waiting for materials to be delivered on site	1	2	3	4	5
Q2.13	Waiting for skilled workers to be provided on site	1	2	3	4	5
Q2.14	Waiting for the clarification and confirmation by client and consultants	1	2	3	4	5
Q2.15	Time for reworks/ repaired works/ defective works	1	2	3	4	5
Q2.16	Time for workers’ rest during construction	1	2	3	4	5
Q2.17	Time for supervising and inspecting the construction works	1	2	3	4	5
Q2.18	Time for instructions and communication between engineers and workers	1	2	3	4	5
Q2.19	Time for transporting workers, equipment and materials	1	2	3	4	5

According to your experience, how much has the project performance cost been affected due to these wastes in your recently completed project? Please fill in the cell below.

	Question	%
Q2.20	How much has the project performance cost been affected due to these wastes compared to the expected cost (in percent)?	……

PART 3: Identification of Possible Causes of Waste

According to your experience, what is the frequency of occurrence of the mentioned activities on construction sites? Please circle the number following scale below:

"1" = "Most unlikely", "2" = "Unlikely",

"3" = "Likely", "4" = "Most likely"

#	Waste causes	Answer			
Q3.1	Poor coordination among project participants	1	2	3	4
Q3.2	Poor planning and scheduling	1	2	3	4
Q3.3	Lack of control	1	2	3	4
Q3.4	Bureaucracy	1	2	3	4
Q3.5	Lack of trade skills	1	2	3	4
Q3.6	Inexperience inspectors	1	2	3	4
Q3.7	Too few supervisors/ foreman	1	2	3	4
Q3.8	Supervision too late	1	2	3	4
Q3.9	Poor labor/ worker/ equipment distribution	1	2	3	4
Q3.10	Inappropriate construction methods	1	2	3	4
Q3.11	Outdated equipment	1	2	3	4
Q3.12	Equipment shortage	1	2	3	4
Q3.13	Poor equipment choice or ineffective equipment	1	2	3	4
Q3.14	Poor site layout and setting out	1	2	3	4
Q3.15	Poor site documentation	1	2	3	4
Q3.16	Poor material delivery schedule	1	2	3	4
Q3.17	Poor quality of materials	1	2	3	4
Q3.18	Inappropriate/ misuse of materials	1	2	3	4
Q3.19	Poor storage of materials	1	2	3	4
Q3.20	Poor material handling on site	1	2	3	4
Q3.21	Defective or wrong information	1	2	3	4
Q3.22	Late information and decision making	1	2	3	4
Q3.23	Unclear information	1	2	3	4

PART 4: Cause-and-effect relationship

According to your experience, please indicate the most likely factor that causes the waste occurrence on construction sites. Please mark "X" to the cell for your choice.

#	Waste factors	Causes: Management cause	People causes	Performance causes	Material causes	Information causes
Q4.1	Over-allocated/ unnecessary equipment on site					
Q4.2	Over-allocated/ unnecessary materials on site					
Q4.3	Over-allocated/ unnecessary workers on site					
Q4.4	Unnecessary procedures and working protocols					
Q4.5	Material lost/ stolen from site during construction period					
Q4.6	Material deteriorated/ damaged during construction period					
Q4.7	Mishandling or errors in construction applications/ installations					
Q4.8	Materials for reworks/ repaired works/ defective works					
Q4.9	Accidents on site					
Q4.10	Waiting for others to complete their works before the proceeding works can be carried out					
Q4.11	Waiting for equipment to be delivered on site					
Q4.12	Waiting for materials to be delivered on site					
Q4.13	Waiting for skilled workers to be provided on site					
Q4.14	Waiting for the clarification and confirmation by client and consultants					
Q4.15	Time for reworks/ repaired works/ defective works					
Q4.16	Time for workers' rest during construction					
Q4.17	Time for supervising and inspecting the construction works					
Q4.18	Time for instructions and communication between engineers and workers					
Q4.19	Time for transporting workers, equipment and materials					

PART 5: Personal Information

Please tell the researcher some information about you. (Please circle the option you choose).

Q5.1 Your current position of work?

a. Project/ site manager b. Team leader c. Site engineer d. Others

Q5.2 How many project you have involved?

a. One b. Two c. Three d. >= Four

Q5.3 Type of project stakeholder you are working for?

a. Owner b. Consultant c. Contractor d. Others

Q5.4 Number of years involved in construction field?

a. <=3 years b. 3-6 years c. 6-9 years d. >= 9 years

Q5.5 Are you concerned about waste problems in your construction site? Please indicate your answer according to the following scale:

1. Much unattended 2. Little unattended 3. Normal 4. Little attended 5. Much attended

--- THANK YOU ---

Any inquiry/comment/suggestion, please reply to the author via address below:
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APPENDIX 2

RESULTS OF PREDICTION BY ANN AND LR MODEL

No	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Project Cost Loss		
																				Actual	ANN	LR
1	5	4	4	5	5	4	3	3	4	4	5	5	3	5	3	4	4	3	4	9.0	9.68	9.77
2	2	2	3	2	3	3	3	2	3	2	3	3	4	3	3	4	3	3	3	8.0	8.80	9.01
3	2	2	2	2	2	2	2	2	3	2	3	3	3	3	3	3	3	3	3	5.0	4.63	4.82
4	3	2	4	2	3	3	4	2	4	2	3	3	3	3	3	2	4	3	3	12.0	11.59	11.52
5	2	1	3	2	3	2	3	1	1	1	2	3	2	2	2	3	1	3	2	8.0	8.29	8.36
6	3	3	2	2	2	2	3	2	2	3	2	2	3	1	2	2	4	3	3	9.0	8.88	8.76
7	3	2	1	5	4	4	4	4	3	4	2	2	4	2	3	3	3	4	4	12.0	11.54	11.57
8	1	2	2	2	2	3	2	2	3	1	2	3	2	3	2	2	2	3	2	8.0	8.74	9.00
9	4	3	3	4	4	3	3	3	2	1	3	2	4	3	2	2	4	5	1	10.0	9.15	8.93
10	2	2	2	1	2	3	3	2	1	1	2	2	2	2	2	3	2	3	2	8.0	8.40	8.70
11	2	3	2	3	3	2	3	2	3	3	4	4	2	2	5	1	3	3	2	10.0	9.58	9.53
12	3	3	3	4	2	3	3	4	3	3	3	4	3	3	3	3	4	3	4	9.0	9.89	9.64
13	3	2	3	5	4	5	3	5	3	3	3	4	4	5	3	3	5	4	4	10.0	10.09	10.17
14	2	1	4	2	5	2	4	2	2	2	3	2	4	3	4	4	2	3	4	10.0	9.88	9.80
15	3	4	2	3	3	2	3	3	4	2	3	4	2	4	3	3	5	4	4	9.0	9.34	9.74
16	3	4	3	4	4	5	3	3	3	3	4	3	5	4	4	4	4	3	4	10.0	9.88	9.72

17	2	2	2	2	3	3	2	2	2	4	4	3	2	3	2	1	2	4	3	7.0	6.66	6.72
18	4	4	3	4	4	4	3	3	3	3	3	3	3	3	3	3	4	3	4	10.0	9.60	9.48
19	2	2	2	3	4	4	4	4	2	4	3	2	4	3	2	2	3	3	3	5.0	5.58	5.41
20	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	4	12.0	11.58	11.75
21	2	2	2	1	2	2	3	3	2	3	3	2	3	2	1	1	2	2	2	8.0	8.48	8.71
22	2	2	2	3	3	4	3	3	4	4	3	3	5	2	2	5	1	4	2	10.0	8.98	8.68
23	3	3	3	3	4	4	4	3	3	4	3	3	4	3	2	2	4	5	4	9.0	9.42	9.43
24	4	4	4	5	5	5	5	5	2	4	4	4	5	4	4	4	5	3	5	12.0	11.22	11.46
25	2	1	2	3	3	3	2	3	2	1	2	1	1	2	3	2	3	2	3	8.0	8.59	8.92
26	2	1	2	2	3	2	1	3	3	1	2	3	4	2	3	2	1	4	2	8.0	8.59	8.18
27	2	1	2	1	4	1	1	2	3	2	1	2	1	3	2	4	3	3	3	7.0	8.36	7.82
28	4	2	5	3	2	3	4	1	3	2	1	2	3	2	4	2	3	2	1	10.0	9.39	9.43
29	3	4	4	4	4	3	4	4	3	3	4	4	3	4	4	3	4	3	3	10.0	10.15	9.99
30	3	3	3	2	2	4	4	2	4	4	2	3	2	3	3	4	2	3	4	9.0	9.40	9.57
31	2	3	2	2	2	2	2	3	2	2	2	2	3	2	2	3	3	2	2	8.0	8.46	8.69
32	2	1	2	3	3	4	3	3	2	3	2	4	1	3	1	2	4	2	1	10.0	9.86	9.69
33	2	1	1	1	2	1	2	1	1	2	1	1	1	2	3	4	1	1	1	8.0	8.30	7.93
34	2	1	1	5	2	3	2	1	1	3	4	5	5	1	2	1	3	3	2	9.0	9.09	8.68
35	2	3	2	3	2	1	2	2	2	2	1	1	2	1	1	1	2	2	2	8.0	8.28	8.31
36	4	4	4	4	4	4	3	4	4	3	3	3	2	3	4	4	2	2	4	10.0	9.55	9.47
37	5	5	5	4	4	4	4	4	3	3	4	4	4	4	3	2	4	3	3	11.0	10.87	10.94
38	1	1	1	2	4	3	2	2	2	3	3	3	2	2	3	3	3	3	4	6.0	8.64	8.71
39	1	1	1	4	4	4	3	3	2	4	4	4	3	4	3	2	2	2	4	10.0	9.79	9.55
40	2	3	3	3	4	4	3	3	2	4	4	4	3	4	3	3	3	3	4	9.0	9.63	9.47

41	4	3	4	5	3	3	4	3	3	4	4	4	3	4	2	1	3	4	4	10.0	9.92	9.54
42	4	3	3	3	4	4	4	3	4	3	3	4	4	2	4	4	5	4	3	10.0	9.82	9.77
43	2	3	3	3	4	3	4	3	2	3	2	3	1	2	2	2	3	2	3	9.0	9.51	9.46
44	4	4	3	5	4	4	4	4	4	4	3	3	5	4	3	3	5	5	4	10.0	9.90	9.92
45	4	4	4	4	3	4	4	4	3	3	3	3	5	3	4	4	4	5	5	9.0	9.21	9.67
46	2	2	2	1	4	5	3	3	3	4	4	5	3	5	3	3	3	4	4	10.0	9.93	9.61
47	3	3	4	3	2	3	4	2	3	3	3	4	2	3	4	1	4	4	1	12.0	9.85	10.03
48	5	1	4	2	3	2	3	4	1	4	3	2	4	4	2	3	3	2	4	9.0	8.81	8.38
49	2	3	3	3	4	4	3	3	2	4	4	4	3	3	2	3	4	4	4	9.0	9.23	9.33
50	2	2	1	2	3	4	3	2	1	3	2	1	3	1	3	4	2	1	2	8.0	8.53	8.83
51	3	3	3	3	4	5	3	3	3	4	3	3	4	3	4	3	4	4	4	10.0	9.66	9.61
52	2	2	2	3	4	4	3	3	2	3	3	3	4	4	2	2	3	3	4	5.0	5.27	5.24
53	5	3	4	4	3	4	4	3	4	4	3	4	4	3	4	3	4	4	3	10.0	9.85	9.87
54	4	4	2	2	2	2	2	2	2	3	4	4	3	3	2	2	4	3	3	9.0	9.09	8.86
55	3	3	3	3	4	4	3	3	2	4	3	3	3	4	2	2	3	3	3	10.0	9.23	9.33
56	4	3	4	3	2	3	4	2	3	2	3	2	3	3	2	3	2	3	2	8.0	9.00	9.04
57	3	4	4	5	5	4	4	4	2	4	4	4	5	4	3	5	4	5	4	9.0	9.62	9.54
58	4	4	5	3	5	3	4	4	5	4	3	4	3	5	5	4	2	4	4	10.0	9.58	9.78
59	3	2	2	5	5	5	4	3	3	4	5	5	3	3	2	1	5	2	2	12.0	9.98	10.44
60	3	3	3	4	4	5	3	3	3	4	3	3	4	2	3	3	3	3	4	9.0	9.61	9.37
61	2	2	2	2	4	3	3	3	3	2	3	3	3	1	2	2	3	3	4	7.0	8.77	8.89
62	3	4	3	3	4	4	4	4	3	4	4	5	5	4	3	3	5	4	5	10.0	10.11	10.00
63	3	3	3	5	4	4	4	3	2	4	5	5	3	2	3	2	4	4	4	10.0	9.78	9.74
64	2	4	2	4	3	3	2	4	2	3	2	4	4	4	3	2	3	3	3	10.0	9.78	9.43

65	3	3	3	3	4	4	3	3	3	4	3	3	3	4	3	3	3	4	3	9.0	9.26	9.39
66	4	5	4	4	4	3	4	4	4	4	4	3	4	2	2	3	2	4	3	9.0	9.09	9.16
67	1	1	1	3	2	2	2	2	2	4	3	4	3	3	1	1	3	4	2	8.0	8.68	8.87
68	3	4	4	5	5	4	4	3	5	4	3	4	2	5	2	2	4	3	5	10.0	9.97	10.21
69	2	3	2	3	4	4	5	3	3	2	3	4	4	2	4	3	4	2	2	10.0	10.19	10.18
70	4	4	3	2	5	3	3	5	3	4	3	4	5	5	4	4	4	4	2	9.0	9.46	9.62
71	3	3	3	4	4	4	4	4	4	3	4	4	4	4	3	4	5	4	5	12.0	10.04	9.94
72	3	3	3	3	2	3	3	4	3	4	4	4	4	4	3	3	4	4	3	10.0	9.69	9.56
73	4	4	4	3	3	4	3	3	3	4	4	4	3	3	4	3	4	4	3	10.0	9.79	9.59
74	4	4	3	4	3	3	3	3	3	4	4	4	4	3	3	3	3	3	3	9.0	9.34	9.35
75	3	3	3	4	4	4	4	3	4	3	4	4	4	3	3	3	4	3	3	10.0	10.09	9.85
76	2	4	3	3	3	3	4	4	3	3	4	3	3	4	2	2	3	2	2	10.0	9.99	9.74
77	2	1	1	2	4	3	4	4	2	3	4	4	3	4	3	4	3	4	4	9.0	9.33	9.34
78	3	3	3	2	3	3	3	3	3	3	4	4	4	3	3	3	3	3	3	10.0	10.16	10.22
79	3	3	3	3	4	4	4	3	2	4	4	3	3	2	2	2	3	4	4	9.0	9.13	9.24
80	4	3	4	4	4	4	3	3	2	3	3	3	3	3	4	4	2	4	3	5.0	5.01	5.08
81	4	4	4	4	4	3	3	3	5	4	4	4	4	3	5	1	5	5	5	10.0	9.94	9.74
82	1	2	3	3	3	1	2	3	4	1	2	3	4	4	3	2	3	4	5	9.0	9.14	8.74
83	2	3	4	3	2	3	4	4	4	2	3	2	4	4	3	3	4	3	2	12.0	12.87	12.77
84	3	3	3	3	4	3	3	3	2	4	4	4	3	3	2	2	3	3	2	9.0	9.01	9.20
85	3	3	2	3	3	3	2	3	3	2	3	3	4	4	3	2	2	2	3	9.0	9.20	9.10
86	4	4	4	4	4	4	4	4	3	5	5	5	4	5	3	3	5	5	5	10.0	10.13	10.01
87	3	3	3	4	4	4	4	4	3	4	4	4	4	4	3	3	3	4	3	10.0	10.09	9.76
88	2	4	3	3	2	4	3	3	3	2	3	2	3	3	4	3	4	3	4	10.0	9.79	9.61

89	3	3	2	4	2	3	3	2	3	2	3	2	2	4	4	4	3	4	3	9.0	8.88	9.36
90	2	2	2	4	4	3	3	2	4	4	3	4	3	2	4	5	4	3	3	9.0	9.46	9.38
91	3	2	2	3	3	4	4	4	2	4	4	4	4	5	3	3	4	3	3	12.0	10.03	9.99
92	3	4	2	3	3	3	4	4	2	4	3	3	3	3	3	3	3	3	3	10.0	9.69	9.55
93	4	4	3	3	3	3	3	4	2	5	3	4	4	3	2	3	3	4	3	9.0	9.06	9.15
94	3	3	3	3	4	3	2	4	4	3	2	4	2	3	3	2	2	4	4	9.0	8.95	9.13
95	3	3	4	4	3	4	5	2	4	4	3	4	3	3	3	2	4	3	2	10.0	10.18	10.31
96	4	3	3	3	2	3	3	4	4	2	3	4	3	2	4	4	2	4	4	8.0	9.06	9.21
97	3	3	4	3	3	2	3	4	5	2	3	4	2	4	2	3	2	3	4	9.0	9.26	9.20
98	3	3	3	4	4	3	3	4	3	4	3	5	2	4	4	4	4	4	2	10.0	9.91	9.81
99	3	3	4	2	2	3	4	4	3	3	2	4	3	3	3	4	4	3	2	15.0	14.87	14.75
100	3	4	4	4	4	3	3	4	3	4	3	3	3	2	3	3	5	1	2	9.0	9.82	9.67
101	4	5	3	2	4	3	5	3	4	2	3	4	2	1	4	4	2	3	3	10.0	9.80	9.41
102	4	4	3	3	4	3	2	4	3	4	4	4	4	4	3	4	4	3	3	9.0	9.14	9.24
103	3	3	2	4	4	4	4	2	2	3	4	2	3	3	4	2	3	3	3	12.0	11.53	11.48
104	2	3	4	2	3	3	1	3	3	3	3	3	4	4	3	2	5	3	4	9.0	8.95	9.11
105	3	3	4	3	3	3	4	2	2	4	3	3	2	3	3	3	4	1	3	10.0	9.49	9.61
106	4	2	3	3	3	4	3	2	4	3	4	2	4	4	4	4	4	4	4	9.0	8.94	9.24
107	4	4	3	3	4	3	3	4	2	3	3	3	4	2	4	2	3	3	3	8.0	9.13	9.25
108	2	4	4	3	2	3	4	3	2	3	2	2	1	2	3	4	4	4	3	12.0	11.37	11.46
109	4	3	2	4	4	4	3	2	3	4	4	4	4	3	2	5	4	4	4	6.0	6.16	6.12
110	4	4	3	4	4	3	2	4	3	3	4	2	4	4	4	3	4	3	2	10.0	10.07	10.29
111	3	3	4	4	3	3	3	3	2	3	4	2	2	4	1	4	2	5	3	8.0	8.85	8.46
112	3	3	3	4	2	5	3	4	4	1	3	4	2	2	2	4	3	4	4	10.0	9.98	9.41

113	4	4	4	4	3	3	4	3	2	2	3	4	4	3	2	4	4	3	3	9.0	9.35	9.47
114	2	3	4	2	2	4	2	3	4	3	4	2	4	4	3	2	2	3	4	10.0	9.98	10.07
115	3	3	4	4	4	4	3	2	3	3	4	2	3	4	4	3	3	4	2	9.0	9.33	9.28
116	2	2	3	2	3	4	2	2	2	2	2	1	3	3	3	2	2	4	4	8.0	9.06	8.52
117	1	5	2	3	2	3	4	2	4	3	2	3	4	3	3	3	3	4	2	12.0	12.86	12.64
118	5	3	2	4	3	2	4	2	3	3	2	2	4	2	3	2	3	4	4	9.0	8.90	8.95
119	2	3	4	4	3	2	3	2	3	5	3	4	3	4	4	4	3	3	4	5.0	5.96	5.42
120	3	4	2	4	1	3	2	4	2	3	4	2	4	3	4	2	2	4	3	9.0	9.11	9.08
121	2	4	3	3	3	4	2	4	2	2	3	4	3	4	4	2	4	3	3	10.0	9.98	9.77
122	2	2	3	3	4	3	4	3	3	4	3	2	3	3	4	4	3	2	5	12.0	11.29	11.34
123	3	4	3	4	4	5	3	2	2	3	2	4	2	2	2	3	3	4	3	8.0	9.49	9.35
124	4	4	4	3	2	4	4	4	3	3	4	4	4	3	4	4	4	4	3	7.0	7.80	7.89
125	3	2	3	4	4	3	2	4	3	2	3	4	4	4	3	4	3	4	2	9.0	8.94	9.09
126	4	4	2	3	3	4	2	3	4	4	3	2	3	4	4	1	2	3	3	10.0	9.41	9.38
127	3	4	3	2	4	2	4	2	3	2	3	4	2	4	4	2	2	3	3	12.0	12.44	12.42
128	4	4	3	4	4	4	4	2	2	3	4	2	3	3	4	4	2	4	4	9.0	9.10	9.12

CURRICULUM VITAE

1. Personal Information

- Name: **Ha Duy Khanh**
- Sex: Male
- Date of Birth: October 05, 1986
- Marital status: Single
- Nationality: Vietnamese
- Email: hd.khanh@hotmail
- Corresponding mailing address: Department of Civil Engineering, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, Ward 14, District 10, Ho Chi Minh City, Vietnam.

2. Education

- 2004 – 2009: Bachelor of Civil Engineering, Department of Civil Engineering, Ho Chi Minh City University of Technology (HCMUT), Vietnam National University – Ho Chi Minh City.
    - Thesis title: *"Structural Design for CN6 Mixed-Use Apartment Building Project."*
    - Advisor: Assoc. Prof. Nguyen Van Hiep
    - Date of defense: January 2009
    - Date of graduation: April 2009 (GPA: 8.11/10.0, rank: 4/99)

2009 – 2011: Master of Engineering, Division of Construction Engineering and Management, Department of Civil Engineering, Ho Chi Minh City University of Technology (HCMUT), Vietnam National University – Ho Chi Minh City.

  - Thesis title: *"Survey and Propose Solutions to Prevent Waste Occurrence during Construction Phase of High-Rise Projects."*
  - Advisor: Assoc. Prof. Pham Hong Luan
  - Date of defense: January 2011
  - Date of graduation: April 2011 (GPA: 7.65/10.0)

- 2012 – 2014: Doctor of Philosophy, Interdisciplinary Program of Construction Engineering and Management, Department of Civil Engineering, Pukyong National University, Busan, South Korea.
  - Thesis title: *"Waste Problems in Vietnam Construction Industry Based on Lean Philosophy."*
  - Advisor: Prof. Kim Soo Yong
  - Date of defense: December 2013
  - Date of graduation: February 2014 (GPA: 4.42/4.5)

3. Achievement during master course

- Ha Duy Khanh, Pham Hong Luan, (2011). "Survey and Propose Solutions to Reduce the Waste during Construction Period of High-Rise Buildings in Ho Chi Minh City." *Journal of Ministry of Construction,* No. 520, pp. 64-68, June 2011 (Vietnamese).

- Ha Duy Khanh, Nguyen Van Hiep, (2011). "Pre-stressed Concrete Spun Pile: Define Loading Capability and Deformation, and Evaluate the Use Effectiveness (BS Standard)." *Journal of Ministry of Construction,* No. 521, pp. 74-79, July 2011 (Vietnamese).

4. Achievement during doctor course

a. Journal papers

- Ha Duy Khanh, Soo Yong Kim, (2012). "Identifying Causes for Waste Factors in High-Rise Building Projects: A Survey in Vietnam." *KSCE Journal of Civil Engineering* (Accepted for publication in Vol.20, No.5/ May 2014).

- Ha Duy Khanh, Soo Yong Kim, (2012). "Determining Labor Productivity Diagram in High-Rise Building Using Straight-Line Model." *KSCE Journal of Civil Engineering* (Accepted for publication in Vol. 20, No.5/ May 2014).

- Ha Duy Khanh, Soo Yong Kim, (2013). "Barriers of Last Planner System: A Survey in Vietnam Construction Industry." *Korean Journal of Construction Engineering and Project Management* (KICEM), Vol. 3, No. 4, pp. 5-11.

- Ha Duy Khanh, Soo Yong Kim, (2013). "Evaluating Impact of Waste Factors on Project Performance Cost in Vietnam." *KSCE Journal of Civil Engineering* (Accepted for publication in Vol.20, No.6/ June 2014).

- Ha Duy Khanh, Soo Yong Kim, (2013). "Examining Applicability of Last Planner System in Vietnam Construction Industry." *KSCE Journal of Civil Engineering* (Under review).

- Ha Duy Khanh, Soo Yong Kim, (2013). "Relationship between Waste Occurrence and Production Planning in Construction Projects." *Korean Journal of Construction Engineering and Project Management* (KICEM) (Under review).

- Rahman MD. Mizanur, Ha Duy Khanh, Lee Young Dai, (2013). "Development of Time-Cost Models for Building Construction Projects in Bangladesh." *Korean Journal of Construction Engineering and Project Management* (KICEM) (Under review).

- Ha Duy Khanh, Soo Yong Kim, (2014). "Development of Waste Occurrence Level Indicator in Vietnam Construction Industry." *Engineering, Construction and Architectural Management,* Emerald Publisher (Under review).

- Rahman MD. Mizanur, Ha Duy Khanh, Lee Young Dai, (2014). "Investigation of Main Causes for Schedule Delay in Construction Projects in Bangladesh." *Korean Journal of Construction Engineering and Project Management* (KICEM) (Under review).

b. Conference papers

- Ha Duy Khanh, Soo Yong Kim, (2012). "Waste Factors in High-Rise Building Projects: A Case Study in Vietnam." *Annual Conference of Korea Institute of Construction Engineering and Management,* Kyongpook National University, Daegu, Korea, 11 October 2012.

- Ha Duy Khanh, Soo Yong Kim, (2013). "Relationship between Labor Productivity and Design Characteristics in High-Rise Buildings." *Proceedings of the 1st International Conference on*

Research Methodology for Built Environment and Engineering (ICRMBEE), Kuala Lumpur, Malaysia, 17~18 December, 2013.

- Rahman MD. Mizanur, Lee Young Dai, Ha Duy Khanh, (2013). "Verification of Time-Cost Relationship for Building Construction Projects in Bangladesh." *Annual Convention of Korea Society of Civil Engineers* (KSCE), Gwangwon, Korea, 23~25 October, 2013.

- Ha Duy Khanh, Soo Yong Kim, (2013). "A Literature Review on Causes of Design Change during Construction Phase of Project." *Annual Conference of Korea Institute of Construction Engineering and Management,* Dankuk University, Suwon, Gyeonggi, Korea, 10 November, 2013.

5. Working experience

- Site engineer, Quoc Cuong House Development and Investment Co., Ltd. in Ho Chi Minh City, Vietnam.
  - Project name: Quoc Cuong 1 High-rise Apartment Building.
  - Scope of work: supervision for civil works.
  - Total investment: 5.5 million USD.
  - Duration: February 2009 – January 2010.

- Leader of structural design team, Quoc Cuong House Development and Investment Co., Ltd. in Ho Chi Minh City, Vietnam.
  - Project name: 6B High-rise Building Project; Belleza Apartment Building; Dai Phu Apartment Project; Chu Manh Trinh Hotel Project; Giai Viet Aprtment Project; Hoa Phat Factory Project;

Ly Tu Trong Hotel Project; Intresco Hai Au Project; Ngoc Dong Duong Mid-Rise Apartment Project.

- Scope of work: structural design, or design inspection.
- Duration: February 2010 – October 2010.

- Site engineer, Trung Dung Construction Co., Ltd. in Ho Chi Minh City, Vietnam.
  - Project name: Canary Apartment Project (9.5 million USD); and Jabil Vietnam New Factory Project (22.0 million USD).
  - Scope of work: quantity surveyor, coordinative engineer, project team leader, and site manager's assistant.
  - Duration: October 2010 – February 2012.

6. Language and computing skills

- Foreign language: Good in English.
- Computing software: AUTOCAD, SAP, ETAB, MATLAB, MS Project, MS Office, Crystal Ball, SPSS.