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COST BASED VALUE STREAM MAPPING AS A LEAN CONSTRUCTION TOOL FOR UNDERGROUND PIPELINE CONSTRUCTION PROJECTS

BY

AYMAN FAHMI NASER

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COMMITTEE PAGE

The members of the Committee approve the Thesis of Ayman Fahmi Naser defended on 05/12/ 2017

Dr. Murat Gunduz
Thesis Supervisor

Dr. Galal M. Abdella
Chair

Dr. Farayi Musharavati
Internal Examiner

Dr. Irtishad Ahmad
External Examiner

Approved:

Khalifa Al-Khalifa, Dean, College of Engineering

ABSTRACT

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Title: Cost Based of Value Stream Mapping as a Lean Construction Tool for Underground Pipeline Construction Projects.

Supervisor of Thesis: Murat Gunduz.

Contractors want to improve the construction productivity and utilize an efficient, cost calculation which assists the company to get accurate cost that can be presented during next estimation for similar construction projects. This study deals with the application of Value Stream Mapping (VSM) as a lean construction tool on a real construction for installation of underground pipelines. VSM was adapted to reduce the high percentage of non-value added activities and time wastes during each construction stage, and the study searched for an efficient, way to consider the cost of e the studied underground pipeline. This review is unique in its approach that it adopts cost implementation of VSM to improve the productivity of underground pipeline projects.

A real construction project was observed and relevant data were collected from the site during construction, indicating the value added, non-value added and process time for each construction stage. The current state was built based on these details. This is a process management tool and exercise to keep opening eyes as a trigger for improvement. After a current state assessment, a future state is attempted by value stream mapping tool balancing the resources using a line of balance (LOB) technique. This study is unique in its way that it adopts cost and LOB implementation of VSM to improve the productivity of underground pipeline projects. Moreover, a cost estimation model was developed during current state and future state to calculate the cost of constructing the underground pipeline. The results show a cost reduction of 20.8 % between current and future states. This reflects the importance of the cost based value stream mapping in construction as a useful tool. This new tool could be utilized in the construction industry to improve the efficiency and cost management.

DEDICATION

I would like to thank

ALLAH Almighty for His countless blessings…

My Parents for their Prayers and Encouragements

You spent everything, for us, me and my brothers and sisters...

My Brothers and Sister who believed in me...

My lovely wife Lubna for the endless Support and Love ….

My Sons and Daughter, looking into your eyes gave my all hope in Great future...

And to you; who is giving me your time reading this work …

To all of you this work is Dedicated.

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Thanks to ***Almighty ALLAH*** for giving the strength and ability to understand, learn and complete this Thesis.

In gratitude and wish sincere thanks to my supervisor ***Dr. Murat Gunduz***, for his help, support and guidance throughout the last two years. Your motivation and guidance was the reason for this thesis to become a reality.

Everlasting thanks to our instructors at ***Qatar University***, for the years we spent together and learned more and more from you.

Special thanks to ***My Colleagues*** and ***My Friends***, who helped me through the difficult times, I couldn't achieve anything without their support …

Thanks All

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CHAPTER 1: INTRODUCTION

1.1 Overview

Value Stream Mapping (VSM) is a new phrase that originates from Toyota's material and information flow diagrams and was designed to help Toyota's suppliers learn the Toyota Production System (Rother et al. 2003). VSM is a lean-management method to analyze the current state and to design a future state for the series of events that take a product or service from its beginning through to the customer.

VSM is not just only a tool and limited to identify waste in a system, but it is used to analyze and aid in designing processes, tracing material flow, and documenting information flow of a given product or product family. VSM adapts symbols to represent a clear and visual process from the customer's requirement to the final accomplishment.

The application of VSM in the construction industry has inattentive consideration due to the difficulty in implementation of VSM in real construction activities. In this study, underground pipeline project was practically studied to evaluate the effectiveness of VSM as a lean construction method.

In this context, cost-based value stream mapping is developed to take into consideration the owner value as the reference and guide. The cost-based value stream mapping develops the implementation of value stream mapping to build an optimized future state with less cost.

Cost based on value stream mapping considers the customer value as the guide which basically eliminates the time wastes to get more production with high quality.

Consequently, the integration of value stream mapping and costing methods were used to develop an infrastructure work for a structure implementation of the VSM approach. Therefore, through field surveillance, construction stage modeling according to VSM and cost based VSM were able to improve the value added and the overall productivity.

Although several papers and researches addressed using VSM as a lean tool to reduce waste and maximize the value added during the construction process, no detailed and unified VSM instructions exist to implement it in construction considering the cost of construction. Hence, the contribution of this study to existing knowledge can be stated as the introduction of a cost-based VSM methodology in underground pipeline projects.

1.2 Statement of Problem

The construction industry is suffering from delay and cost overrun worldwide. The delays in construction are time wastes oriented, caused by unproductive work, idle manpower and equipment time. Construction industry produces huge amounts of time wastes that negatively affect the economy.

A large number of studies related to delay in construction projects have been conducted shows that lean management tools have been used to overcome and minimize the delays. Past studies did not apply VSM and cost together. In this study, the cost based VSM technique was utilized on a real construction project.

The construction of underground pipelines is one of the construction types that produce a huge amount of time wastes which lead to delay in the project completion dates. For this study, underground pipelines were selected as a case due to the repetitiveness of the construction activities and less complexity in the entire construction.

This thesis attempts to identify, develop and apply a concept of cost-based VSM in the construction sector, which can serve as a new way forward for future cost estimation.

1.3 Scope and Methodology

In this research, the concept of cost reduction was addressed in construction by utilizing a value stream mapping. More specifically, value stream mapping (VSM) was applied on the real case study for construction of underground pipelines. The construction processes were optimized based on the cost according to value stream mapping technique. This was achieved by comparing a cost of the current state with a cost of future state, which attempts to appraise the objective of value stream mapping in construction. The same concept can be set as a model for proper utilization and estimation to similar repetitive projects in future.

The very first step in this study is to form a comprehensive current state for the construction process. This is a vital step as it lays the ground for a full understanding the processes in construction and finds out the time wastes. By the value stream mapping concept, the wastes were measured and identified in the current state. Then, the future state was formulated accordingly to improve the productivity and reduce the time wastes. Work plan and required manpower were set according to feedback from the current state to optimize the process and ensure wastes are minimized in combination with the line of balance technique (LOB).

In this research and in line with the concept of value stream mapping, the approach of cost-based VSM in construction is identified and established. The cost-based of value stream mapping is computed on a weekly basis, and it takes into consideration all costs related to value stream mapping activities.

The cost calculation was done for current and future states, and then the comparison between them has been evaluated for estimation and bidding purpose for similar future projects. Figure 1 shows methodology for this study:

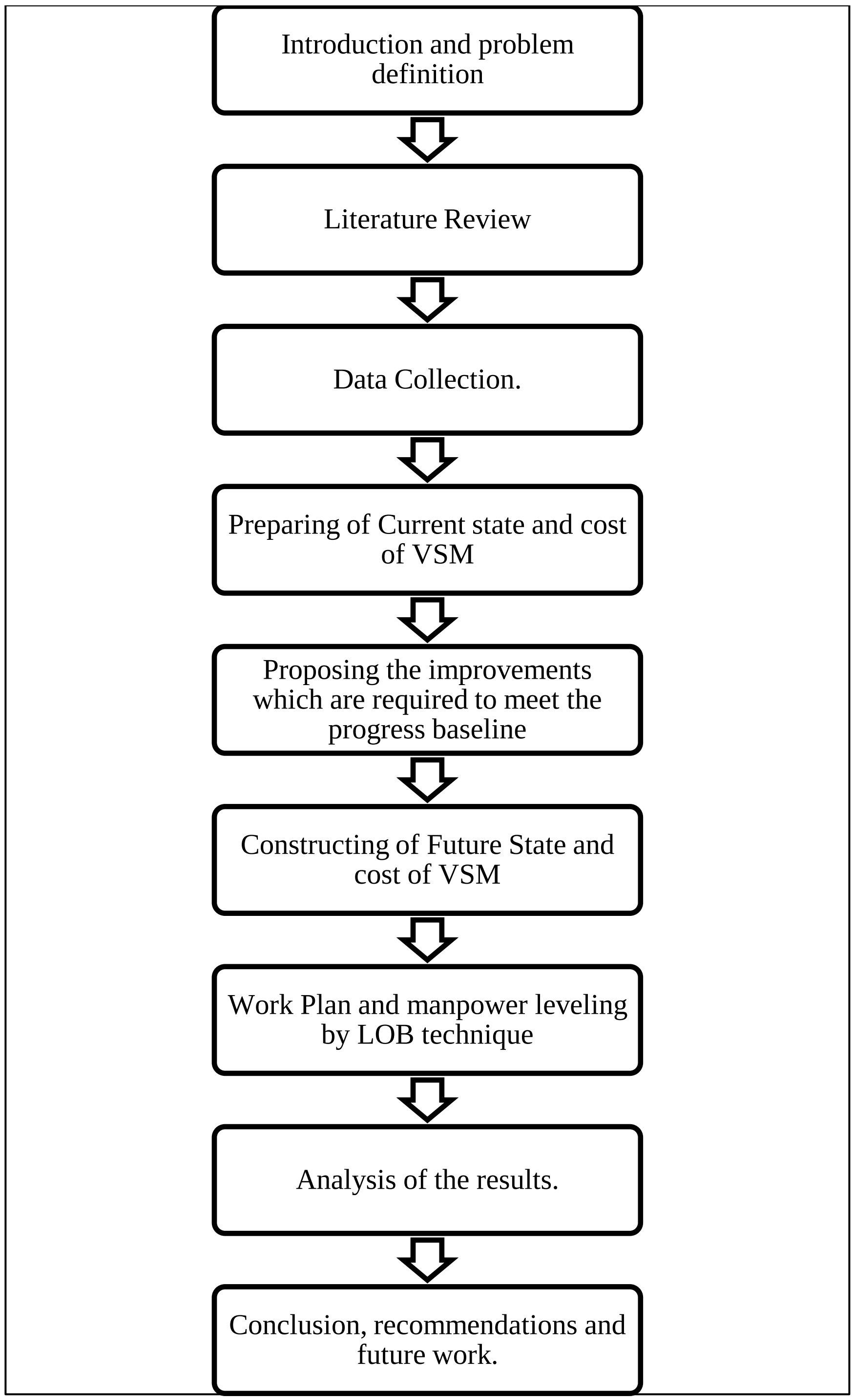

Figure 1. Research Frame Work

1.4 Objective

The objectives of the research are to:

- Recognize the importance of the application of value stream mapping in the construction industry by applying the concept to a real construction project.
- Introduce and evaluate the implementation of a cost-based VSM in the construction industry.
- Evaluate the effectiveness ofe the integration of VSM, LOB, and cost based VSM as a tool to improve the value-added and reduce the time wastes in construction activities.
- Validate and suggest future state mapping based on the improved results for future standardization.

1.5 Report Organization

This study comprises of six chapters:

1. Chapter 1 presents the introduction to the research done. This is composed of the overview, objectives, problem statement, methodology and the thesis organization.

2. Chapter 2 furnishes a brief of studies had been done in the past on the utilization of value stream mapping in construction. Moreover, it describes the VSM and its various implementations and how it can be an essential tool to reduce the time wastes (non-value added) and cost overruns in the construction industry.

3. Chapter 3 is an exploration of the research methodology employed in the study.

Data collection, formulation of the current state of VSM and calculation of the cost based on current state are explained in this chapter.

4. Chapter 4 discusses the current state of VSM and formulates the future state, resource leveling by LOB technique and calculates the cost based VSM.

5. Chapter 5 discusses the results.

6. Chapter 6 conclusion, recommendations, and future work.

CHAPTER 2: LITERATURE REVIEW

Chapter two presents the summary of studies had been done in the past on the utilization of value stream mapping in construction. As well as describes the VSM concept and shows the various implementations on how it can be an essential tool to reduce the time wastes (non-value added) and cost in the construction industry. Moreover, it describes how the characteristics of previous researchers and studies were employed in this research.

2.1 Value Stream Mapping

The concept of value stream was first used in the book "*The Machine that Changed the World"* (1990) by Womack, Jones, and Roos, and more elaborated in "*Lean Thinking"* (1996) by Womack and Jones. Afterwards, book by Martin and Osterling, the authors defined: "a value stream is the sequence of activities an organization undertakes to deliver on a customer request." (Osterling and Martin, 2013). Further details, "a value stream is the sequence of activities required to design, produce, and deliver a good or service to a customer, and it includes the dual flows of information and material." (Osterling and Martin, 2013). The activities in a value stream can be the work performed by the organization itself, as well as the work performed by outside parties; even the customers can be a part of a value stream. There are different types of the value stream.

The main type is one that a good or service is requested by and finally delivered to an end customer. A value-enabling or support value stream is a value stream that supports the delivery of value (e.g., IT support, hiring, product design).

Before learning the tools used in VSM to eliminate waste, an understanding of the types of waste that might occur is necessary. There are three types of operations that are undertaken (Monden, 2011): "(1) value adding; (2) non-value adding; and (3) necessary but non-value-adding". The first operation is the process that is converting raw materials into the final product by using the needed resources. The second one is pure waste with unnecessary actions that should be completely eliminated. The third one involves actions that are necessary but might be wasteful. According to Jones (1995), there are seven wastes in the Toyota production system. They are faster-than-necessary pace, waiting, conveyance, processing, excess stock, unnecessary motion and correction of mistakes.

In the manufacturing environment, VSM has been discussed since the technique was employed at Toyota Motor Company, and was recognized as "material and information flows." The improvement of manufacturing performance in Toyota focuses on recognizing the process flow of information and material during manufacturing. Pictorial representations with process maps are ways to communicate with different parties in an organization. In this way, value stream maps can provide a whole view of how to work being done through the entire systems.

"Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA" written by Rother et al. (2003) and "*Value Stream Mapping: How to Visualize Work Flow and Align People for Organizational Transformation"* written by Osterling and Martin (2013) present the following benefits of Value Stream Mapping:

(1) Provides a holistic view of the entire flow: By mapping the value stream, a more appropriate understanding of the entire process can be achieved. The act of connecting separate parts into a more holistic system helps the team to identify both the necessary and unnecessary functions, allowing the latter to be either removed or changed for better process flow. VSM also helps to discover any potential information problems that are not easily identified within the production system. Visualizing non-visible works such as information exchanges are important in understanding how work is accomplished.

(2) Identifies Waste: Applying VSM to map the current state of the product or service shows value added and non-value added processes and waste during the production process. What is more, the value stream map can clearly identify the seven most common types of waste: Overproduction, waiting, transport, extra processing, inventory, motion, and defects, all of which are summarized in Table 1.

Table 1

Seven Wastes

Waste	Example
Overproduction	Precast concrete is produced at a level higher than the owner required. This leads to waste and an increase in inventory and waiting time.
Waiting	Work will be delayed due to broken equipment, bad weather.
Transportation	Unnecessary movement of information, products or components from one place to another.
Extra Processing	Following the process accurately to eliminate potential costs in the installation or rework.
Inventory	Unused products wait for further processing. Poor planning will increase the cost of the worksite and occupy valuable warehouse space .
Motion	The poor material layout will produce unnecessary movements by workers on the work site.
Defects	Defective materials and damaged machines can lead to rework and increase costs.

(3) Generates improvement plans: Once wastes are identified in the production process, the team can start building an improvement plan using lean concepts to eliminate waste and to add value. VSM focuses on calculated experimentation in certain parts of the process before disturbing the flow of the rest of the business.

To sum up, value stream maps provide a visual, full-cycle macro view of how work progresses from a customer request to the final fulfillment of that request. The mapping process deepens the understanding of work systems that deliver value to customers and reflect the workflow from a customer's perspective. As a result, the process of value stream mapping provides effective ways to establish strategic directions for better decision making and work design.

Drawing a value stream map is the result of implementing a VSM tool. In the pioneering work of Rother and Shook (2003), the landmark book "*Learning to See"* provided the first way to "see" the value streams that Womack et al. introduced. As stated by Rother and Shook, the process of developing a value stream map can be briefly summarized as:

(1) Identify the target product, process family or service. A process family is a group of products or services that go through the similar or same processing steps or the most problematic process family that needs to be improved.

(2) Draw the current state ofe the process. The map should illustrate how the exact activities are performed in a real working context. To develop a current state map, collect data and information by walking the flow and interviewing the people who perform the tasks. With the information gathered through the process, the current state value stream map can be developed using pre-defined symbols representing different elements in the value stream, which shows the information, process steps required and current delays in delivering the requested service or product to the customer.

(3) Analyze the current state of value stream map. After the current state map is completed, the team may go through the process of assessing the current state value map in terms of developing flow by eliminating waste. In this step, there are several lean

principles that can facilitate the improvement of the value stream (e.g., takt time, continuous flow, etc.).

(4) Draw a future state map. The aim of future value stream mapping is to emphasize on waste sources and the process of eliminating them within a short period of time. The future state map should be formulated according to an assessment of the current state map and make improvements that can be achieved. Through building up a future state value stream, the aim of the desired result can become a truth.

(5) Work toward the future state condition. The plan for future state fulfillment is crucial; otherwise, value stream maps are pointless. A plan for accomplishing the future state value stream can be a future state map, detailed process map, a yearly value stream plan or a combination of those documents.

VSM originated from Toyota's technique diagrams and was designed to help Toyota's suppliers learn the Toyota Production System (Rother et al. 2003). Rother's study and ten years' of experience in operating VSM in various industries have demonstrated that VSM is more than just a tool. VSM was not limited only to identifying waste in a system, but could also be used to analyze and aid in designing processes, tracing material flow, and documenting information flow of a given product or product family. VSM uses symbols to represent a clear and visual process from the customer's requirement to the final accomplishment. Figure 2 below shows the symbols of VSM according to Rother and Shook (2003):

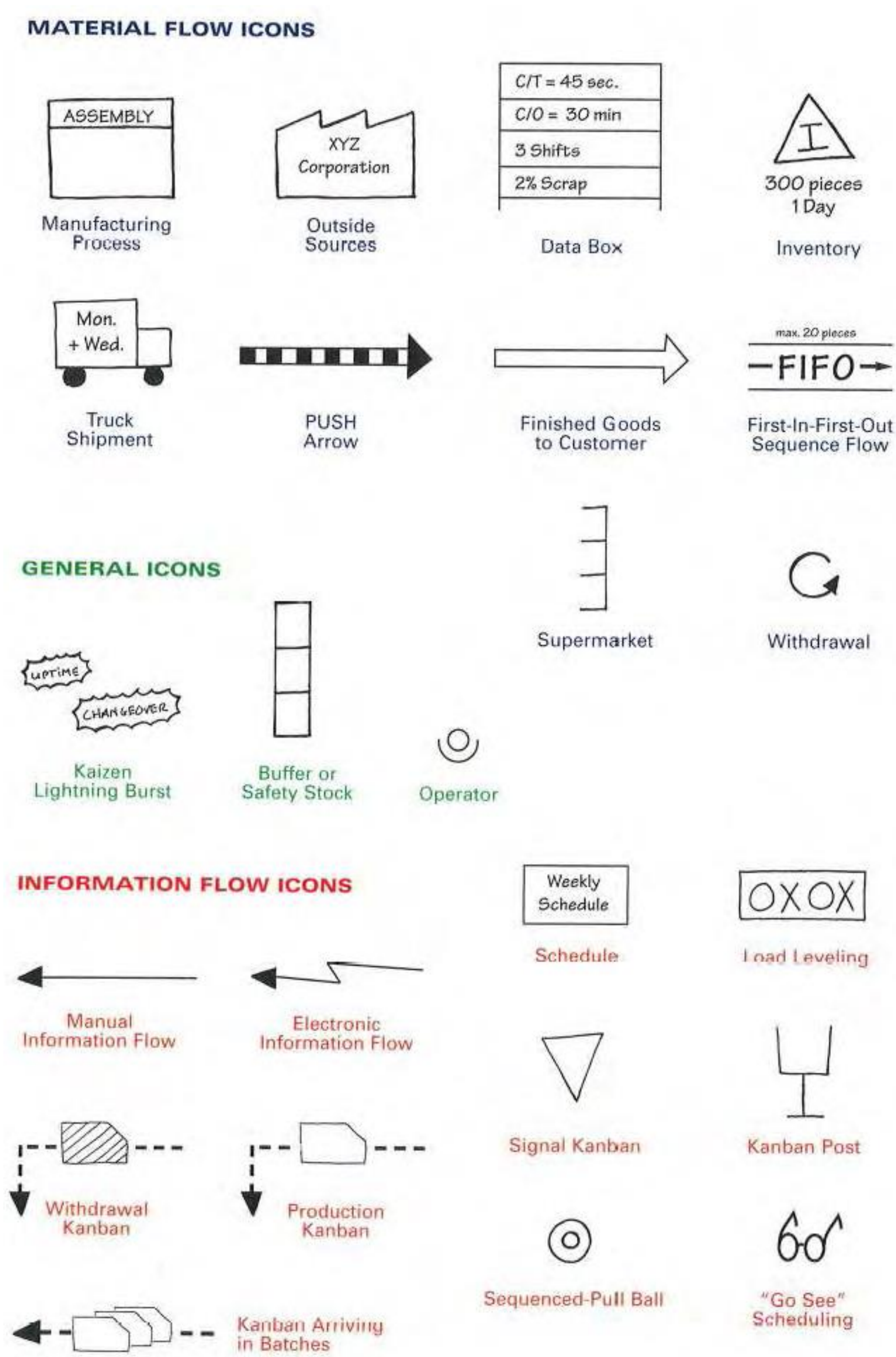

Figure 2. Symbols of VSM according to (Rother and Shook, 2003)

There are five basic steps for applying VSM in various industries. The first step is to define the product family and then draw a current state map of the product. After identifying the non-value added and value-added processes, the team brainstorms, and combined lean concepts with the value added to construct a future state map. The final step is to implement an action plan with a detailed process map, and a yearly value stream plan that could achieve the future state.

Hines and Rich (1997) conducted a study describing the seven VALSAT in terms of the seven wastes mentioned above. The seven tools and their relationships are shown in Table 2 below.

Table 2

The seven value stream mapping tools “Hines and Rich, 1997.”

	Mapping tool						
Wastes/structure	Process activity mapping	Supply chain response matrix	Production variety funnel	Quality filter mapping	Demand amplification mapping	Decision point analysis	Physical structure (a) volume (b) value
Overproduction	L	M		L	M	M	
Waiting	H	H	L		M	M	
Transport	H						L
Inappropriate processing	H		M	L		L	
Unnecessary inventory	M	H	M		H	M	L
Unnecessary motion	H	L					
Defects	L			H			
Overall structure	L	L	M	L	H	M	H

Notes: H =High correlation and usefulness
M = Medium correlation and usefulness
L = Low correlation and usefulness

Hines and Rich (1997) discussed problems related to existing tools for conducting value streams. The seven tools are used to eliminate potential waste and provide a comprehensive view of the value stream in a new and improved configuration. The first tool, Process Activity Mapping, focuses on developing solutions to eliminate waste. The second tool, Supply Chain Response Matrix, identifies activities constraining the process so that these activities can be targeted for elimination or improvement. The third tool, Production Variety Funnel, helps the team understand how products or services are produced. The fourth tool, Quality Filter Mapping, identifies problems related to quality. The fifth tool, Demand Amplification Mapping, shows changes along a supply chain and identifies a decision support system. The sixth tool, Decision Point Analysis, helps identify "the point in the supply chain where actual demand-pull informs forecast-driven push" (Hines and Rich, 1997). The seventh tool, Physical Structure, helps develop a holistic view of the supply chain, for example, understanding how the industry operates and where it might be improved. Using the Value Stream Mapping Analysis Tools (VALSAT) approach is an effective method for selecting the best tool at different steps.

Shou et al. (2016) presented a literature review of the Critical Success Factors (CSFs) in the implementation of VSM across five different sectors: manufacturing, healthcare, construction, product development, and service. The review covers the peer-reviewed journal articles on VSM in Scopus from 1999 to 2015. The findings of this study provide a good basis for industry practitioners to implement VSM effectively.

Jarkko et al. (2014) developed a framework and tested for combining VSM with the evaluation of other parametric values. It was applied in industrialized house-building to improve the production process performance. The developed structure validates the VSM solutions to compare current state with future state designs with reference to production efficiency.

A thorough literature review of VSM shows the importance of adaptation of VSM parameters with respect to each case. VSM parameters can be developed to accommodate the situation to streamline the processes to be leaner.

2.2 Value Stream Mapping in Construction

"Since 1993, the ideas of lean production have been introduced in construction, developing lean construction" (Pasqualini and Zawislak 2005). The implementation of the value stream mapping tool, which represents main principles of lean production, also has been introduced to the construction industry. In spite of being successfully applied to different industries, the application of value stream mapping in construction still has not been fully disseminated. There are few studies about VSM in construction, and they refer more to construction supplies than to the process itself (Fontanini and Picchi 2004).

According to Yu et al. (2009), a number of inhibiting factors for applying value stream mapping to the construction industry include:

1) Repetition of the production process is the main condition to utilize a VSM technique.
2) VSM is a quantitative tool that uses a list of process data to illustrate the current state of the process and to determine what the future state will be. However, most the construction companies usually do not fully track the

construction processes and data.

3) The parameters used in VSM, such as inventory, cycle time, takt time and change-over time are defined in the manufacturing process and not applicable to construction.

Modifications of VSM were necessary due to the differences between manufacturing and construction (Pasqualini and Zawislak 2005). Two examples in previous studies show how VSM can be modified for the application in construction.

The first one is a case study introduced by Pasqualini and Zawislak in 2005. The study described the modified application of VSM in a Brazilian construction company; some adaptations were made in each stage of VSM.

First, each stage in construction occurs over a long period of time and the different processes produce different products. Instead of selecting a family of products to initiate VSM in construction, this study selected a stage of the productive process of construction, which in this case was the masonry stage.

For the current state map, since the time of production in construction is too long to collect in s single day, the way to solve the problem is to obtain the average time of a stage. In the analysis of the current state map, based on the schedule developed from the contract, the takt time can be calculated, which is the effectively available worked time multiplied by the number of square meters to be worked on for the same stage. As a result, takt of the construction will indicate the time in which a square meter should be worked, or the rhythm of production according to the contract states the customer's demand. The concept of this modification is to divide one construction state into units so that the work to be done per unit can be regarded as repetitive, and the flow becomes continuous. Based on the investigation of the current state map, a future state map can be drawn in the same way that occurs in a manufacturing context.

Another example is a case study of housing construction. Yu et al. (2009) worked on a case study of the standard wood platform-frame structure, the case of 400 houses construction was regarded as repetitive works.

Ballard et al. (2001) proposed the main source of waste in construction is due to variability in the process and cycle time can be reduced by balancing the production flow. Bashford et al. (2003) introduced through his research the discussion on the implementation of even flow in the construction process and proposed that the idea had a minor impact on construction activities duration, but may reduce the workflow variability. This study by Yu et al. continues Ballad and Bashford's efforts on house production flow by applying value stream mapping to achieve even flow.

The single building can be seen as a single product family because it was constructed following similar processing steps. However, the level of mapping should be determined since the building construction process is a complex system that consists of hundreds of activities and involves a lot of trade contractors. In construction, the houses do not move along a production line but, rather, workers move from one house to another.

Consequently, the operations done by a trade crew can be regarded as a continuous flow. In this case, one house production process was divided into five stages after considering the size of the value stream map, logical relationship and the total duration of the construction activities. The five stages are the foundation, lock-up, interior and siding, pre-finals and finals. After identifying the target stage to be improved, which is the foundation stage, in this case, a current state map can be drawn.

The future state map can be developed after the investigating of the current state map, during which waste is identified. The focus of the future state map is to eliminate the cause of waste and improve the value stream into a smooth flow. Four measures were taken in the future state mapping. They are establishing a production flow and synchronizing it to takt time; leveling production at the pacemaker task; restructuring work and improving operational reliability with work standardization, and total quality management for this study.

These cases demonstrate that VSM is a tool used to identify the sources of environmental and production waste, quantify them, and suggest reduction strategies. VSM application in construction is hindered by the following identified factors:

(1) A hidden essential for effective VSM is the reoccurrence the construction process.

(2) The current state of VSM is a quantitative tool that uses a list of process data to portray and figure out the future state. However, most construction companies do not totally track construction processes and data.

(3) Key parameters used in VSM, such as inventory, cycle time, takt time and change-over time, are defined in the manufacturing industry; this differs from the construction context (Yu, Tweed, Al-Hussein and

Nasseri, 2009).

Therefore, modifications of VSM are necessary, due to the differences between manufacturing and construction (Pasqualini and Zawislak 2005). Pasqualini and Zawislak (2005) utilized a modified Value Stream Mapping and made some adjustments at each stage to enhance the production process in a Brazilian construction company. Yu et al. (2009) used the modified VSM to reduce waste in housing construction. In this study, the products of production home building were considered as a single product family, because they were constructed following similar processing steps and sharing the same sub-contractors. On a construction site, houses do not move along a production line; however, workers move from one house to another. Thus, the operations performed by a trade crew can be viewed as a continuous flow. In this case, one house production process was divided into five stages after considering the size of the value stream map, logical relationships and the total duration of the construction activities. These five stages were the foundation, lock-up, interior and siding, pre-finals and finals. After identifying the target stage to be improved, which is the foundation stage, in this case, a current state map can be drawn.

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Jarkko et al. (2014) indicated that VSM unable to illustrate a product features other than those associated with production flow. On another hand, parametric VSM enhances the application of VSM.

The above thorough literature shows the importance of implementation of VSM in construction as a lean management tool to reduce the time wastes and increase the value added to the processes.

2.3 Line of Balance in Lean Construction

The Line of Balance (LOB) Technique was originated by the Goodyear Company in the early 1940's and was developed by the U.S. Navy in the early 1950's for the programming and control of both repetitive and non-repetitive projects. It was developed for industrial manufacturing and production control. The main principles of LOB have been employed in the construction industry as a resource is driven planning and scheduling tool.

Lean Construction assumes a process model consisting of material and information flows, from raw inputs to finished products, encompassing activities like transportation, waiting, processing and inspection. Waiting, inspection and transportation are activities that do not add value to the final product (Formoso, 2001). Effectively, processing activities that add value are those that meet the needs of internal and external customers. For the successful application of Lean Philosophy to construction sites, it is necessary to adopt a new system of work planning to systematically organize all departments within a construction company that contributes to production. Moreover planning, according to Mendes Júnior (1999), is a tool that helps operatives to address their work and therefore should be understood and used by them. Losso and Araújo (1995) maintain that there are several methods of planning and control for civil construction, among which stand out simple techniques, such as the Bar Charts or Gantt Charts up to PERT/CPM Networks that might be appropriate for complex jobs. However, when the project is repetitive in nature, the technique most appropriate for planning and control is Line of Balance, by taking advantage of continuity of work.

In simple terms, Line of Balance graphically represents the activities of a process sequenced over time, considering the repetitive nature of the activities of a construction. Through this tool site managers can better visualize the execution sequence of activities, which may result in improvement of productivity and quality of construction. Recognizing the influence of the philosophy of lean construction industry, this paper aims to analyze their major principles and discuss if they can be taken into consideration by the graphical outcomes of a Line of Balance schedule of works.

A line of balance diagram comprises a series of inclined lines which represent the rate of working between repetitive operations in a construction sequence. It's the best planning method for a repetitive work such as villas or dwelling units, high-rise building, highways, pipeline, tunnels, railway, and it could be deployed for non-repetitive projects as well.

The line of Balance (LOB) is a method of showing the repetitive work that may exist in a project as a single line on a graph. Unlike a bar chart, which shows the duration of a particular activity, a LOB chart shows the rate at which the work that makes up all of the activities has to be undertaken to stay on schedule, the relationship of one trade or process to the subsequent trade or process is defined by the space between the lines (Pai et al. 2013).

Pai et al. (2013), identified the purpose of the LOB method is to ensure that the many activities of a repetitive production process stay “in balance” that is, they are producing at a pace which allows an even flow of the items produced through a process and at a speed compatible with the goals set forth in a plan. The advantages of LOB schedule are as follows

1. Clearly shows the amount of work taking place in a certain area at a specific time of the project.
2. Has the ability to show and optimize the resources used for a large number of repeated activities, executed in several zones or locations.
3. Easier cost and time optimization analysis because of all the information available for each activity in the project.
4. Ease of setup and its superior presentation and visualization.
5. Easier to modify, update and change the schedule.
6. Better managing of all the various sub-contractors in the project.
7. Allows for simpler and clearer resource management and resource optimization functions.
8. Visualization of productivity and location of crews.
9. It allows project managers to see, in the middle of a project, whether they can

meet the schedule if they continue working as they have been.

The LOB is based on the underlying assumption that the rate of production for an activity is uniform. In other words, the production rate of activity is linear where time is plotted on one axis, usually horizontal, and units or stages of activity on the vertical axis. The production rate of activity is the slope of the production line and is expressed in terms of units per time. The LOB method manipulates worker-hour estimates and the optimum sizes of crews to generate the LOB diagram. Worker-hour estimates and optimum crew sizes are usually obtained through direct interaction with a scheduler, the site manager, or related subcontractors who are knowledgeable enough to reflect the actual conditions of a project and of its constituent activities. Once the number of crews and the expected rate of output have been computed for each activity, the LOB diagram can be plotted. The number of units to be produced is plotted against time. Two oblique and parallel lines, whose slope is equal to the actual rate of output will denote the start and finish times respectively of each activity in all the units from the first to the last.

Recently LOB has been associated with lean construction applications, especially as a tool for tactical planning of works. LOB is not only a straightforward graphical device to depict site programming in long, medium and short terms but also as an appropriate graphical tool to represent, induce and make self-evident the application of several lean concept ideas like takt time, minimization of production and transfer batches, buffers transparency, integrated planning of long, medium and short term, production levelling, pull production and inventory minimizing.

The basic principles of lean thinking can be summarized as follows: (a) value specification, (b) alignment in the best sequence of actions that develop value, (c) carrying out these activities without interruption, (d) the rhythm of demand commands the rhythm of production and (e) continuous improvement (Womack and Jones, 1996).

Pacheco and Heineck (2008) adherence to a strict sequence of work provides continuous improvement through the learning effect. It is an example of the integration of LOB with takt process time through the rational distribution of employees throughout a site and strategies to allow flexible work to reduce the takt time during each process.

According to Pinheiro et al. (2009), repeating units of work might cause learning effects, what leads to the reduction in activities duration. The smaller the repeating unit, the greater the learning effect, what reduces also global lead time.

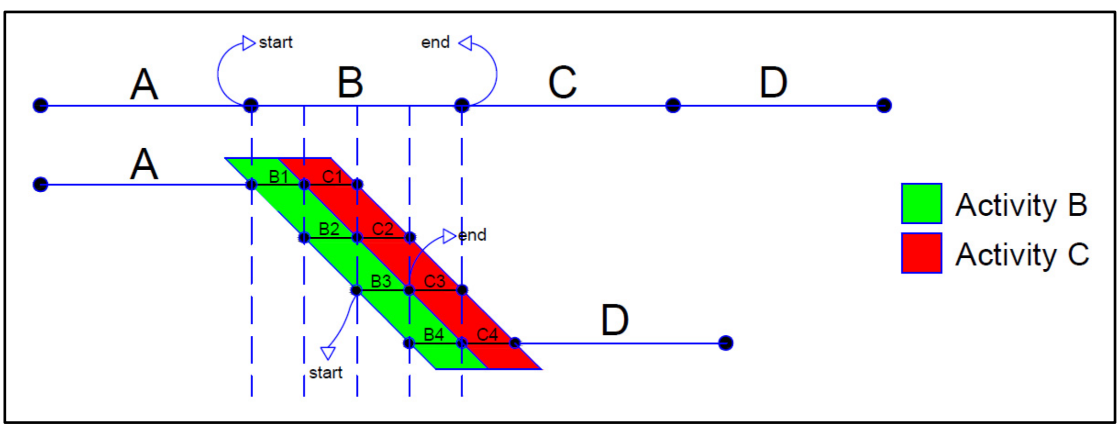

Figure 3. Minimization of production and transfer batches (Pinheiro, 2009)

In drawing LOB, repeatability of cycles is a parameter that comes naturally. This repetition occurs according to the PDCA cycle traversing its four phases: planning, doing, checking and acting. Checking might tell that goals are not being met; acting (reacting) will provide the managerial mechanisms to allow continuous improvement in the next cycles (Pinheiro, 2009).

The literature reviewed papers emphasize on lean philosophy, identifying activities that develop value. Therefore, LOB is studied in order to identify its potential relationship as a resource leveling tool to the principles of VSM in construction.

There is no research shows the benefit of integration of LOB with VSM to calculate the cost based VSM. Thus, this research work utilizes LOB tool as a planning device that gives support to the VSM concept by properly utilizing the resources to calculate the cost based of VSM.

2.4 Cost Based Value Stream Mapping in Construction

Chen et al. (2007) discussed the customer value is the main guide in lean accounting, the main function of value stream shall be eliminating the process time wastes. Lean accounting, lean thinking, and production cannot be separated. Moreover, lean accounting can play a role, only when the lean process has become stable and controllable. Lean accounting helps the development of lean production. However, the lean accounting does not mean the abolition of the traditional accounting system. The traditional accounting system is not wrong, but it applies only to the case of mass production, no longer applies to lean production. The systems lean accounting and traditional accounting adapting to are as shown in Figure 4.

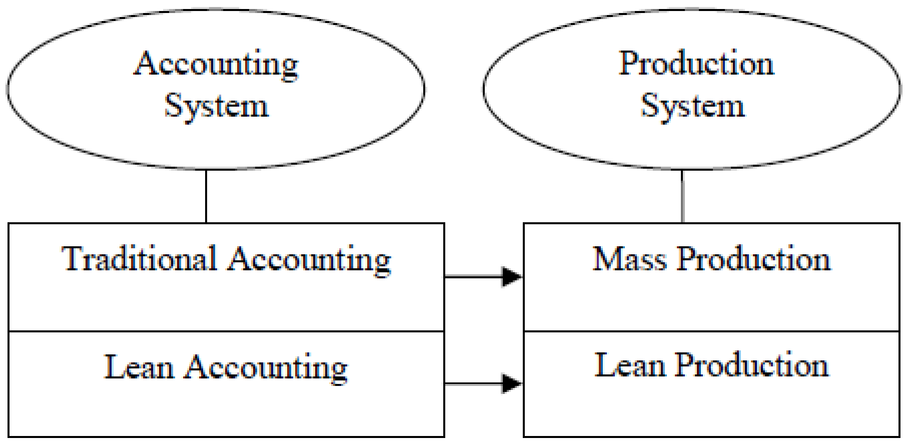

Figure 4. Production system and accounting system

According to Tang et al. (2008) the lean production concept, product cost changes with different combinations of the production and product. Manufacturing expense has a relationship with the value stream rather than labor time individual products spend. The cost of a product depends largely on its flow speed at the entire value stream, especially flow speed at bottlenecks in the value stream. In the pull of customer demand, maximizing the product flow will achieve the maximization of profit in the value stream.

Cost accounting, cost analysis, and cost management will focus on flow speed of products in the value stream rather than the use of resources, personal efficiency or the distribution of manufacturing expense. This not only simplifies the cost accounting, and at the same time makes the activities that generated cost more easily be under control. Therefore, it is necessary for lean accounting to adopt value stream costing method instead of a full-cost method.

Li Bei et al. (2008) identified that value stream cost usually accounts once a week. The content of value stream cost accounting is all consumption in the entire value stream and no longer has direct and indirect cost. All of the value stream cost is considered direct cost, while the cost outside of the value stream is not included in the value stream cost. Cost items include labor cost, materials cost, production support cost, equipment cost, operation support cost, facilities and maintenance cost, all other value stream cost and so on, as shown in figure 5.

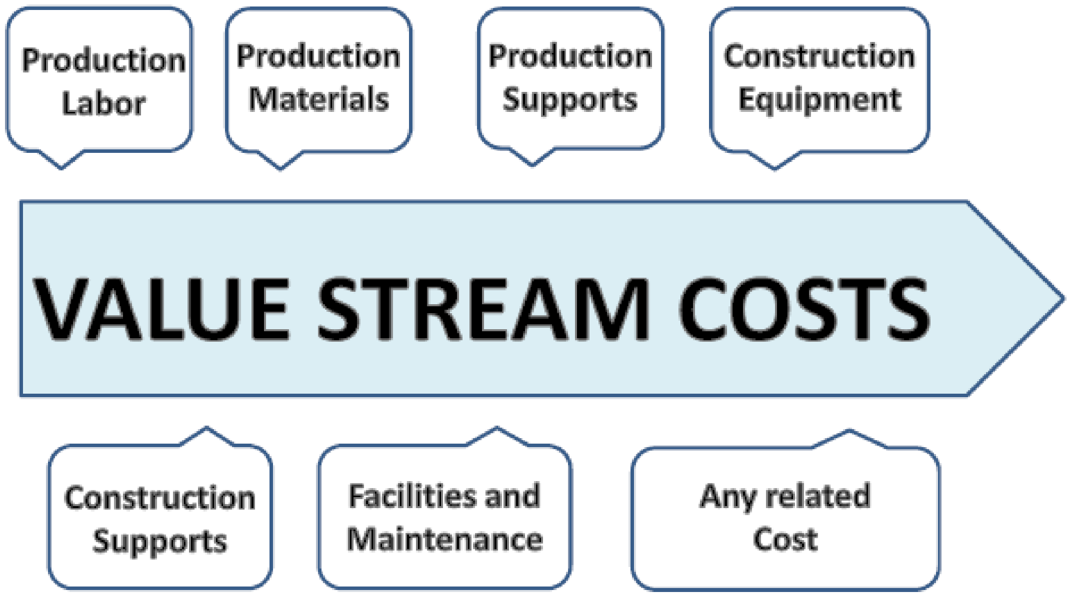

Figure 5. The elements of cost-based VSM

Cost based VSM is easy estimation process because the costs are calculated for the entire value stream and are sum-up over the weekly period. Labor costs are simply the sum of the wages and direct benefits paid to the people working in the value stream, and it is derived from the payroll system.

The elimination of overhead allocations means that the information provided is not complicated by unnecessary application of costs outside the control of the value stream managers. This makes the cost and profit information "real" and understandable to the people working in the value stream and their managers.

The purpose of costing value stream mapping is to eliminate non-useful transactions and reduce non-value added activities. Thus, an adaptation of value stream mapping may reduce the cost and improve the efficiency of the value stream mapping technique.

The following table (3) illustrate different between cost-based value stream mapping and traditional cost calculation (Sheng, 2007):

Table 3

Difference between traditional cost and cost based VSM

Items	Traditional Costing	Cost based VSM
Cost Object	Product	Value Stream
Cost Personnel	Accountants	Competent persons to control the value stream
Cost Analysis Emphasis	Difference analysis	Continuous improvement analysis
Organizational Culture	Command and control	Equality and cooperation
Expense Allocation	Based on workload of workers	Based on value stream
Information Transmission	Upward to managers	Upward, downward or in parallel
Focus	Financial performance	Financial and operational performance

Kim and Kim (2016) explored how ABC can be practically used for construction process improvement with the support of discrete event simulation (DES) technique. Activity hierarchy is presented as a way to allow sustainable activity cost tracking. The paper focuses on presenting how to bridge the gap between activity-based costing and process simulation. For this purpose, the use of appropriate activity hierarchy between two systems and strategy for sustainable process improvement are proposed. As a result, ABC has the limitations in reflecting complicated and interactive nature of construction processes.

As a conclusion, there is no study showing that employed to utilize a VSM to calculate the cost for current and future states in the construction industry. Such studies were concentrated and focused on manufacturing domain only. Introduce a concept of a cost-based VSM in the construction industry will play a significant role in the future construction industry.

2.5 Conclusion

On the whole, although several papers address using VSM as a lean tool to reduce waste and increase the value added during the construction process, no detailed and unified VSM instructions exist concerning how to implement it in construction considering the perspective of cost. As currently understood, VSM needs to be linked with the cost to a better optimal production rate. This study will focus on this perspective.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, methodology steps, tools and techniques that have been developed in this research are discussed.

3.2 Methodology

In the first step, a thorough and comprehensive literature review for the implementation of value stream mapping tool in the construction context was conducted with an emphasis on cost consideration.

This placed the ground for a full understanding of an applicable tool that would be utilized in the construction industry. Thereafter, a real underground pipeline project is introduced in this chapter.

3.2.1 Workflow Diagram and Current State Mapping

In this study, a construction company (XZ) was chosen as a case study to apply a value stream mapping tool in underground pipeline construction work.

The main purpose of selection is the effectiveness of data collection and repetitiveness of the activities.

As per project contract, the scope of work was the construction of pipeline (36-inch diameter) network of 36.5 km.

The first step in the value stream mapping technique is developing a process flow diagram to provide a clear picture about every stage for the construction of the pipeline. Figure 6 shows the main steps for construction of the underground pipeline.

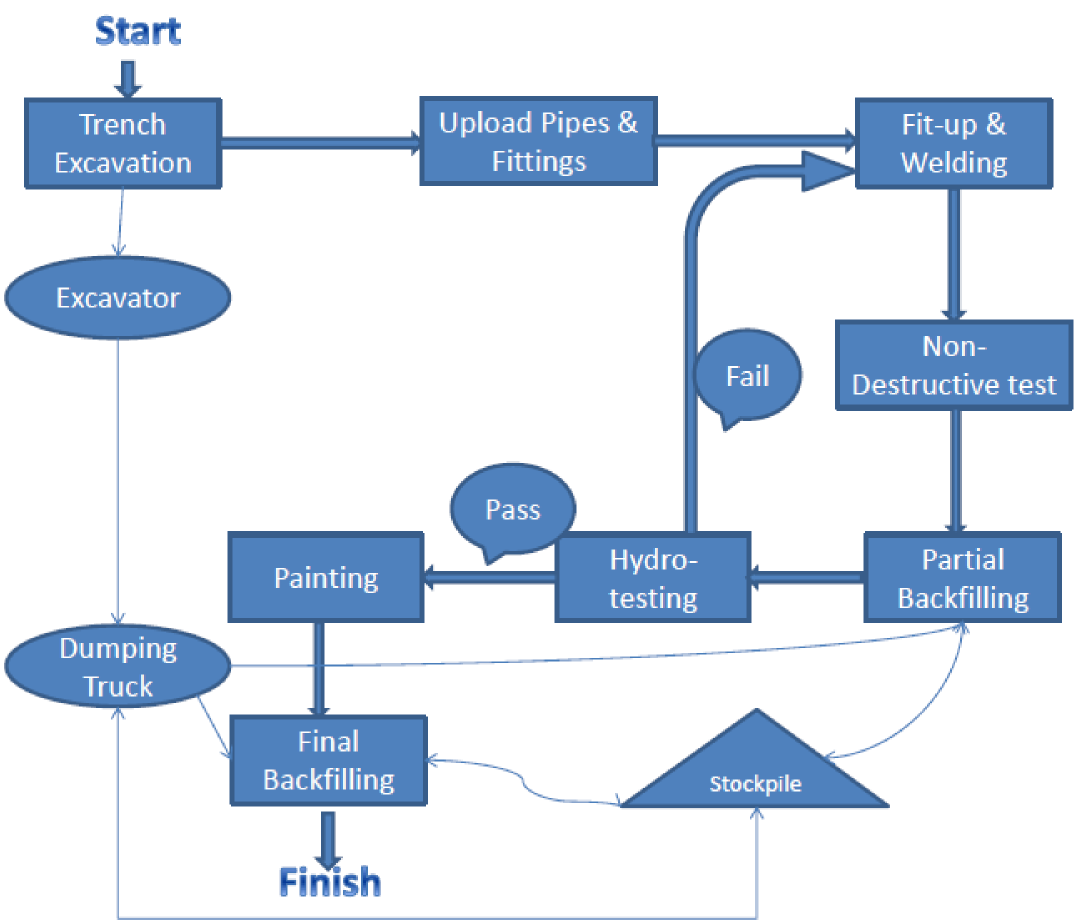

Figure 6. Workflow diagram for construction of underground pipeline

The construction of pipeline requires a lot of coordination from different disciplines. Thus, the data and information were collected to study the flows of material and information. a the beginning, one starts with a quick round of understanding the entire process, and then we repeat the same to gather more information and data in details for each step.

- Excavation: The construction started with the excavation of the required trench provides a safe access and safe trench width. In this case, the required width is 2.5 meter for pipe diameter of 36 inches. Two 30 ton dumping trucks and one excavator were utilized to perform trench excavation. The total time of traveling of the truck and damping material is around 25 minutes. The required supervision is one supervisor, three operators, and three civil workers.

Figure 7. Trench excavation

- Trench bedding: Four laborers perform clearing the trench, manual digging, and necessary general field activities to ensure the trench is in “U” shape and ready to receive the bedding material which is used underneath the pipeline network, refer to below figure 8. The thickness of bedding underneath the pipe shall be 30 cm as a minimum thickness.

Figure 8. Trench preparation "U-shape & pipe bedding."

- Pipe Laying: After the inspection of the trench, the pipes and fittings were shifted by mobile crane and trailer with the assistance of two operators, one supervisor, and two pipe fitters. The required time for shifting the material to site construction is 60 minutes.

- Pipes and fittings fit-up: The fit-up crew (three pipe fitters and one supervisor) is responsible for stringing and aligning the pipe inside the pipeline corridor. The pipe and fitting ends are subject to surface preparation (bevelling) prior to commencing with the first layer of welding.

Figure 9. Shifting pipes inside the trench

Figure 10. Fit-up and stringing in the trench

Figure 11. Pipe bevelling

- Welding: Welding crew consists of two welders and one helper using two fuel operated welding machines mounted on wheels. The welding crew starts with the route; pass and last with cap welding. Every welder who made a joint has a unique identifying number. The numbers are marked in the area adjacent to the pipe, so complete records of the welding are maintained. On the average, the required duration to complete the welding of each joint is 20 hrs working continuously.

Figure 12. Welding activity

- NDT test: After welding, the joint will be ready for non-destructive test (NDT). Normally, the two technicians are hired from Third Party Company to perform the test. The test duration is 80 minutes, and the result will be available after 3 hours.

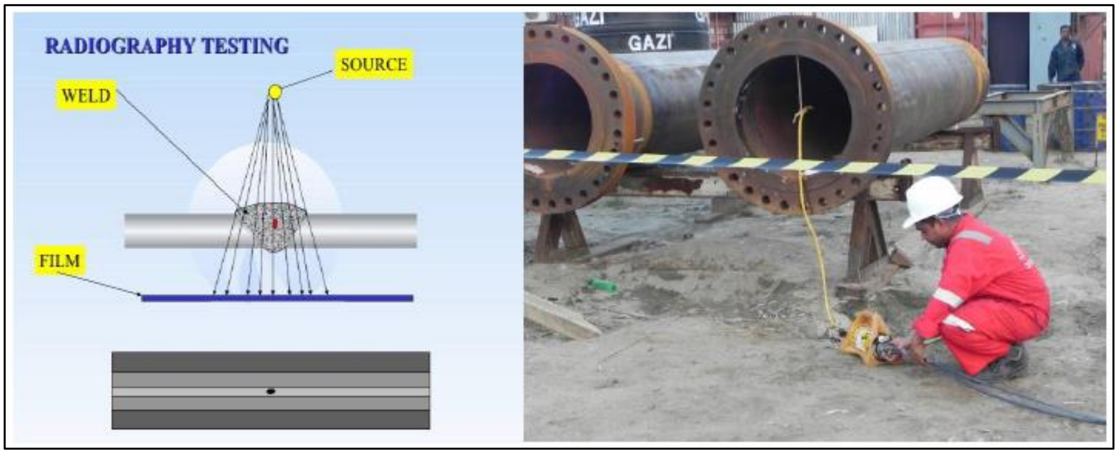

Figure 13. NDT test

- Partial Backfilling: Prior to commencing with hydro-test of the pipeline, the partial backfilling of the pipeline network shall be completed with the assist of three helpers, one supervisor, and two operators. The joints shall be exposed to observe the existing of the leak. The purpose of partial backfilling is to ensure the pipe is anchored and free of any movement or slippage during the hydro-test.

Figure 14. Partial backfilling

- Hydro-testing: As per project specification, the test duration is 24 hours and two hours for test preparation. The maximum pipeline length which is subject to test is specified with 3000 meters. The failure percentage is relatively less than 3 %.

  But if the leak is observed, the line has to be cut and replaced with one short length of pipe; means two joints have to be welded and then perform a test on the line again. One supervisor and three pipe fitters are required to perform the test.

Figure 15. Hydro-testing activity

- Coating: After the test, three painters applied paint for exposed joints prior to proceeding with final backfilling. The total required duration to apply paint and curing is 24 hours.
- Final backfilling: The final backfilling of pipeline network sequence was carried out in layers, and each layer has to be well compacted to ensure the soil and material are uniform distributed. The required time to complete the backfilling is subject to the total length of the pipeline. The final backfilling was conducted by two operators and three civil helpers, with the assistance of one excavator and one compaction equipment.
- With respect to resources, the above-mentioned activities are controlled by the construction managers (1 Civil and 1 Mechanical engineer) and three site engineers

under one project manager to facilitate the workflow for each activity. The following table 4 shows the type and number of manpower were utilized to complete the construction of underground pipeline:

Table 4

Required manpower for construction of underground pipeline

Serial No.	Trade	Number for each
1	Project Manager	1
2	Construction Manager - Civil	1
3	Construction Manager - Mechanical	1
4	Site Engineer	3
5	Supervisor - Mechanical	2
6	Supervisor - Civil	2
7	Supervisor - Painting	1
8	Supervisor - Welding	1
9	Operator	7
10	Civil Worker	10
11	Pipefitter	8
12	Welder	2
13	Helper	4
14	Painter	3
15	NDT technician	2
	Total	48

The workflow shown in figure 6 was rearranged to become a blueprint for current state mapping to show the material and related information flows. This will meet the rule of thumb for the value stream mapping basic concept as shown in figure 16 as a simplified workflow diagram.

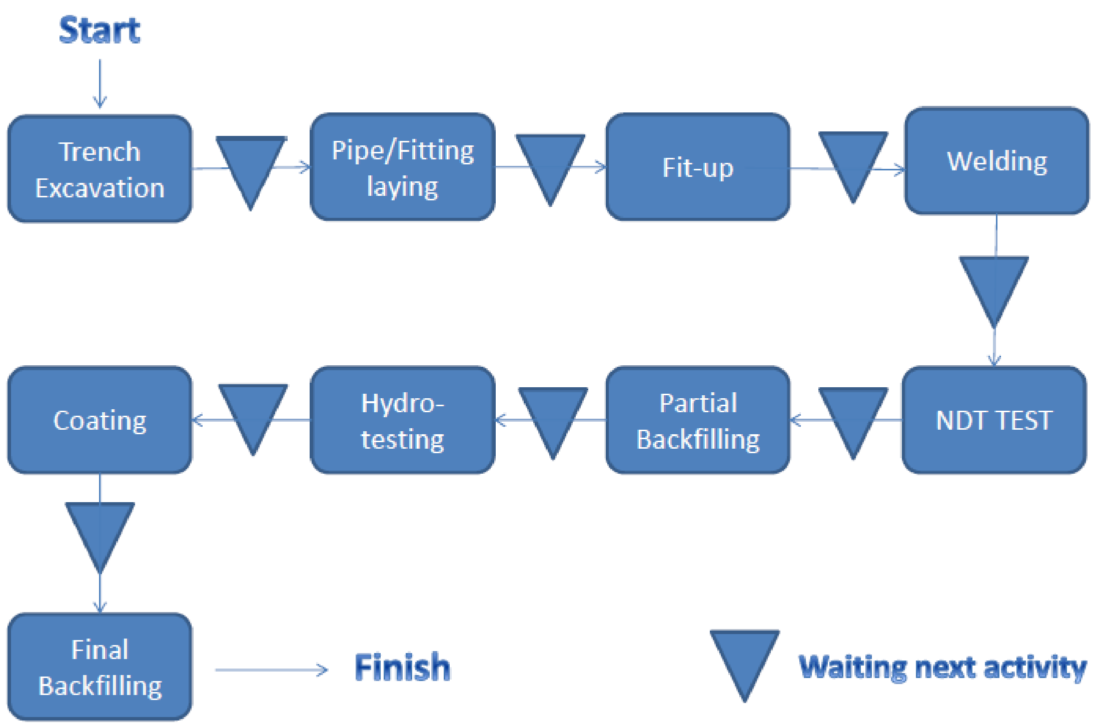

Figure 16. Simplified workflow diagram

3.2.2 Assumptions

To commence with the current state of a value stream mapping, the following assumptions have been considered for this research:

- It is assumed that the signed contract duration is research's reference and baseline in the case study.

- While building a current state of value stream mapping, the systematic concept was adopted during the construction processes.
- It is assumed that raw material is ready to dispatch by suppliers to commence with construction.
- The observation time was focused on the construction of five joints and six pipes as a production capacity to evaluate the value and non-value times during this period.
- The construction contains one shift operation with 10 working hours as an actual working time. It was assumed that there are 26 working days monthly.
- It is assumed the cost of manpower and equipment rates is evaluated in US dollars.

3.2.3 Data Collection

The construction processes were governed by systematic implementation while utilizing a value stream mapping in construction needs some revisions. Therefore, some necessary adaptations and characteristics were developed based on construction environment.

To start with data collection, selection ofe the family of the product has been identified according to value stream mapping concept “Lean construction.”.”.” In the proposed case study, a construction of the pipeline was characterized by a progressive process which produces different products (i.e., shifting materials, backfilling, pipe installation, welding…etc.). Thus, the micro-selection was built based on productive stage and repetitive work for construction of underground of the pipeline network.

Monitoring and recording with stopwatch were conducted to record the actual process time for each construction stage accurately as presented in Appendix A. The below is a brief observation for each stage:

1. Trench excavation: the observed time for excavating the trench is divided into truck loading, haul, dump and return times, plus the time for trench preparation and bedding for pipe installation. Based on the site observation, the average process time is 193 minutes. The excavated material volume per day is 177 m^3, which is enough to place two pipes.
2. Laying pipes and fittings: The required time to shift the pipes or fittings from laydown / store area to site construction was based on site requirements. However, each trip was shifting two pipes or number of fittings, based on site observation, the average process time to shift material is 130 minutes as mentioned in Appendix A.
3. Fit-up: Basically, this process is preparation process prior to welding activity. It is fit-up for the pipe to pipe or pipe to elbow, tee or flange preparation purpose (figure 17). The average process time to perform fit-up is 128 minutes based on site observations.

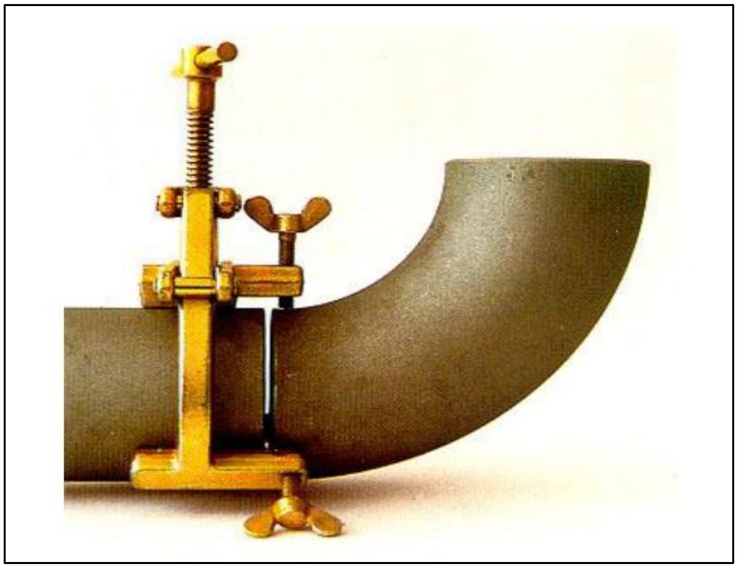

Figure 17. Sample of fit-up

4. Welding: The process was performed by two qualified welders with the assistance of two helpers using welding electrodes and diesel welding machine as equipment to perform the welding joint. The welding process consists of four passes; the first one is root pass, second is a hot pass, third is filling pass, and the fourth step is capping pass as in figure 18. The average required time to complete one joint is 600 minutes.

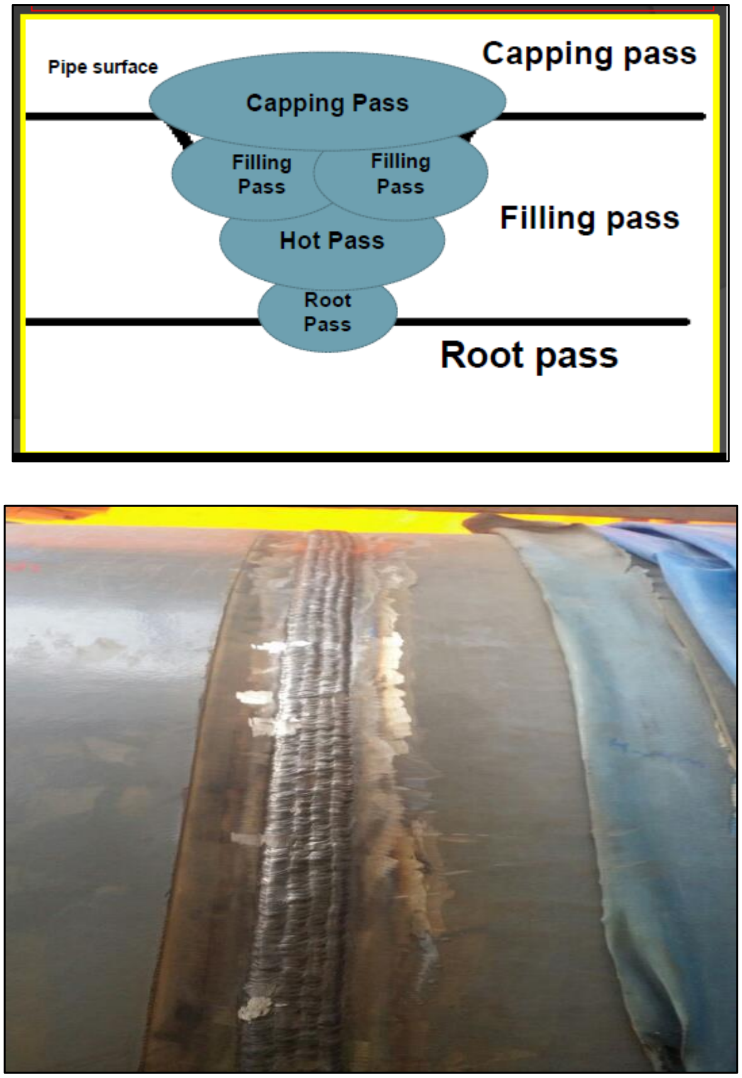

Figure 18. Welding process steps

5. Non-destructive test: In brief, it is a process of radio-graphic test for the welded joint to detect a crack. The schedule was prepared to call NDT technicians after completion of five joints. The test was conducted by a qualified two technicians who are specialized in the radio-graphic tool.

The time was required to perform NDT testing and producing the films is 120 minutes and 200 minutes respectively. Basically, NDT is nonvalue added activity, and it is waiting time only, 5 joins maximum can be done during the night.

6. Partial backfilling: After NDT test, the backfilling and covering of the line will commence immediately to ensure a proper anchorage of the line prior to commencing with hydro-testing. The excavator and truck are utilized with the assistance of three helpers to apply different layers. The welded joints shall be exposed for leak test purpose. The required time to complete partial backfilling is 48 minutes, which is enough to cover two pipes.
7. Hydro-testing: The water filling inside the line was commenced immediately after the completion of partial backfilling. According to project method of construction, the duration of hydro-test is 24 hours. The line will be filled with water gradually to ensure the no air pocket in the line. Then, the line will be pressurized gradually to stabilize with a specified testing pressure for 24 hours; if there is no leak is detected during 24 hours and pressure in the line was stable, the line will be released for next step of joints coating. If the leak is detected, the joint will be subject to rectification (but in this research, the assumption is made based on a happy case scenario). The average time is required for hydro-testing including the preparation is 1561 minutes. This value is including

value added, and non-value added.

8. Painting of the joint: After completion of the hydro-testing, the surface preparation and painting will proceed for the exposed joints. The process consists of surface preparation, apply first and second coats and then last coat with the assistance of three painters. The paint must be cured for at least 10 hours. The averaged required time to complete one joint is 843 minutes.
9. Final backfilling: The last stage in the construction of the pipeline is to complete the covering and grading for the tested line. The excavator, compaction equipment, and truck with the assistance of three helpers participate in the final backfilling stage. The average time required to complete the final backfilling for two pipes with well-graded soil compaction is 601 minutes.

As a result, Table 5 shows the variation in process time for each construction stage to construct two pipes.

Table 5

Process time for each construction stage

Construction Activity	Process Time (Minutes)
Trench Excavation	193.0
Laying Pipes & Fittings	130.0
Fit-up	128.0
Welding	600.0
NDT Test	320.0
Partial Backfilling	48.0
Hydro-testing	1561.0
Painting	843.0
Final Backfilling	601.0

3.2.4 Current Value Stream Mapping

With earlier collected data, the value stream mapping for construction of six pipes can be built based on the value stream mapping concept as discussed earlier in this research. In the beginning, one needs to identify the Value-added and Nonvalue-added for each stage in the construction. As explained previously, the value added is the value of the product which the customer is ready to pay for, which is part of producing the customer's product; such as welding, excavation, block build-up and similar.

In the construction process, high costs and consumption of unnecessary resources generate significant waste and high customer dissatisfaction. Construction industry produces a huge amount of time wastes which affecting the streamlining of the construction activities. Horman (2005) found that 49.6 % of construction time is devoted wasteful activities. All efforts are not added value to the final product called wastes in point view of the client. The source of wastes can be overproduction, waiting, improper stocks, over processing, transportation, unnecessary movement and rework.

The non-added value was classified into two parts:

- Nonvalue-added but required such as inspection.
- Nonvalue-added but not required such as unnecessary transportation.

Recently, the factors affecting the construction activities and delay the completion date are expanded and varies for different causes. It depends widely on the type of construction; methodology adapted availability of qualified manpower…etc. Therefore, remedies for the causes have been studied thoroughly to eliminate time waste for nonvalue-added/not required activity and reduce the time waste for required and nonvalue-added as much as possible.

The value stream mapping was adopted from manufacturing industry to assist in reducing and eliminating the wastes. Globally, the utilization of value stream mapping depicts a vital role in elimination and reduction of time wastes.

Waste means cost and this cost was not considered during estimation or considered during construction. Value stream as a lean tool adapt allocation of cost code according to value stream mapping to evaluate the cost reduction comparing the current state and future state.

The difference between two times is the waste. The waste for each activity is divided into two types:

- Hidden waste: Work that does not add value to the product but which may be required to complete the product; such as change-over, movement without product and transportation.
- Obvious waste: Activities that do not add value to the product and are not required to complete the product; such as scrap, rework, inventory and waiting.

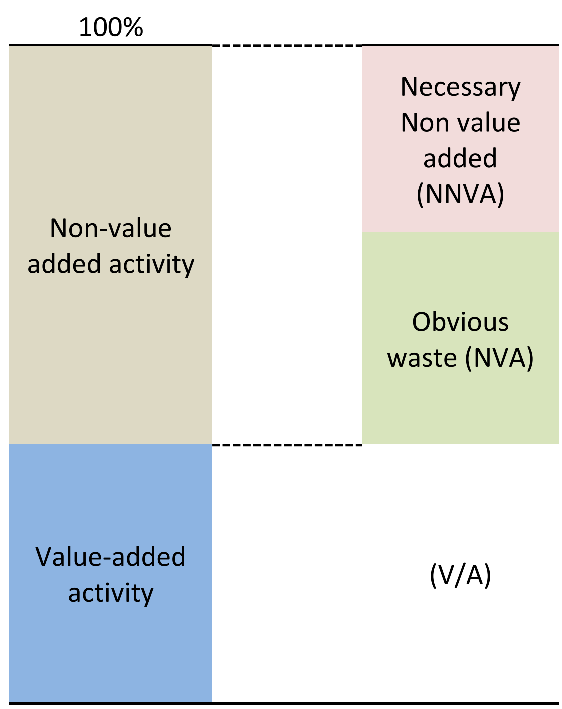

Figure 19. Wastes classification in construction

To explicit in detail, the figure 20 illustrates the type of wastes were generated during construction:

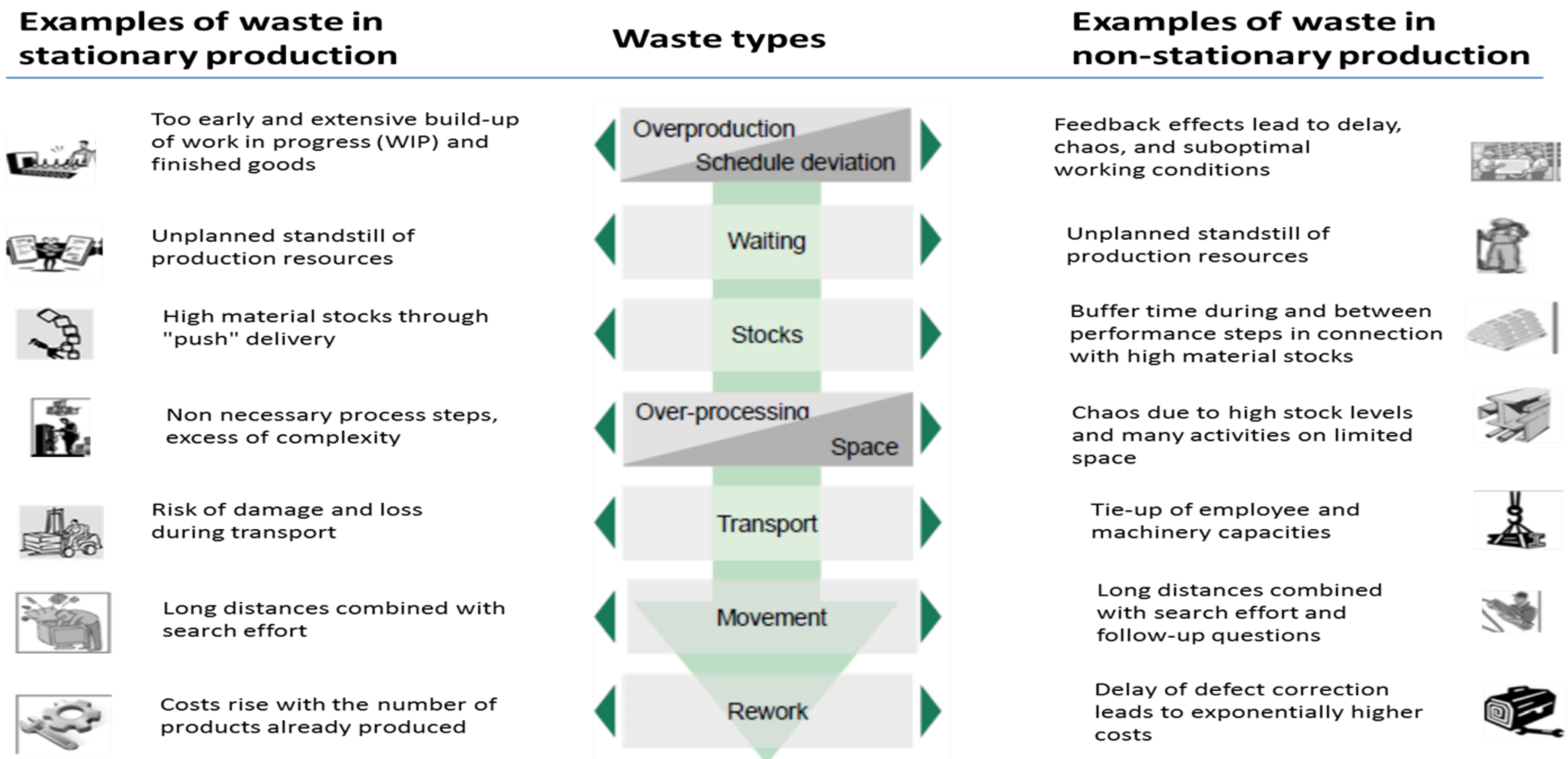

Figure 20. Type of time wastes in construction industry

Figure 21. Samples of time wastes in construction industry

1) Unnecessary movement of information, products or components from one place to another.
2) Unused products wait for further processing. Poor planning will increase the cost of the worksite and occupy valuable warehouse space.
3) The poor material layout will produce unnecessary movements by workers on the work site.
4) Work will be delayed due to broken equipment, bad weather, etc.
5) Precast concrete is produced at a level higher than the owner required. This leads to waste and an increase in inventory and waiting time.
6) Following the process accurately to eliminate potential costs in the installation or rework.
7) Defective materials and damaged machines can lead to rework and increase costs.
8) Failure to develop and utilize the people idea and performance. Comply with standard guidelines.

The main purpose of any construction is to increase the value added (VA) in each stage, minimize the hidden waste and eliminate the obvious waste with respect to the entire process time. Thus, Non-Value Added (NVA) and necessary Non-Value Added (NNVA) must be identified to be able to eliminate the NVA and reduce the NNVA as much as possible.

Thus, the value stream mapping is the most efficient and functional tool which furnish the current state of the construction stages to find out the wastes. This tool envisions optimizing the current state by introducing the future state for the whole system. From the collected data, the following is the current state of construction of the pipeline as shown in figure 22.

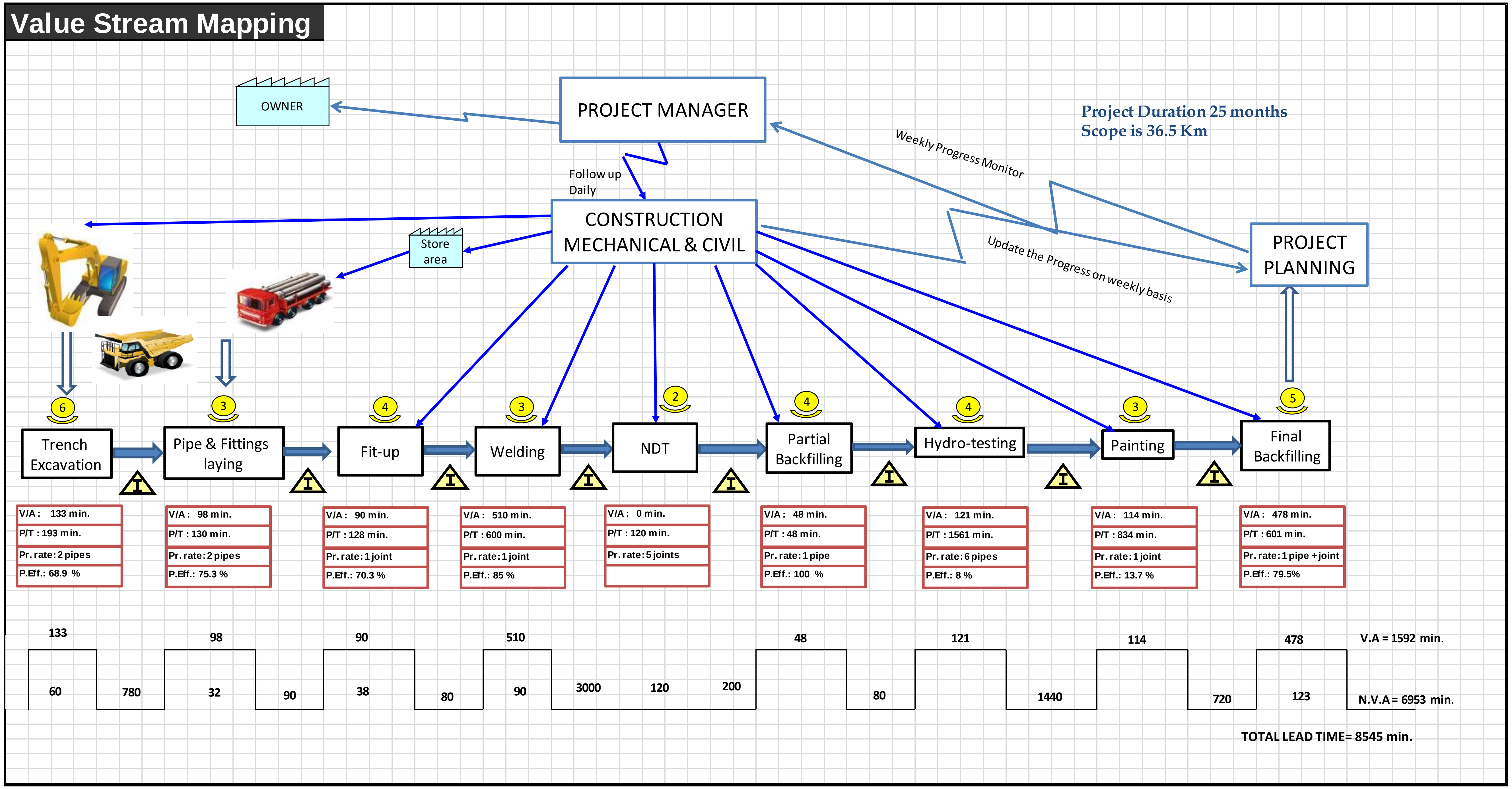

Figure 22. Current state of VSM for construction of underground pipeline

The symbols and icons for current and future states of VSM are illustrated in Appendix B

3.2.5 Takt Time Calculation and Analysis of Current State

A value stream map shows the value added and non-value added for each construction stage as listed in the below table 6. Acknowledge that added value time is the part add value to the final product and the customer is willing to pay for, while the non-added value time is the time which is wasted in the process, and the does not add any value to the final product while the customer is not willing to pay for. In this study, the time was observed for individual activity, the actual time was spent during physical and productive construction was recorded as value added time (VAT) and the time was consumed during non-productive construction such as waiting, idle, rest, standby, etc. was recorded as non-value added time (NVAT).

The percentage of Value Added Time (VAT) is ***18.6 %***. The waste percentage is quite high compared to the total lead time in the construction process. Therefore, the total lead time has to be reduced by enhancing the progress and eliminate the non-value added activity.

Table 6

Non-Value and Value Added Times for each stage

Construction Activity	NVAT (minutes)	VAT (minutes)	Process Time (minutes)
Trench Excavation	60	133	193
Waiting time	780		780
Pipes & Fittings Laying	32	98	130
Waiting time	90		90
Fit-up	38	90	128
Waiting time	80		80
Welding	90	510	600
Waiting time	3000		3000
NDT	320		320
Partial Backfilling	0	48	48
Waiting time	80		80
Hydro-testing	60	121	181
Waiting time	1440		1440
Painting	40	114	154
Waiting time	720		720
Final Backfilling	123	478	601
Total	6953	1592	8545

As mentioned previously, value stream mapping is widely utilized in the manufacturing industry more than construction field. Therefore some aspects were adapted to suit the use of value stream mapping in the construction industry. To define the targeted productivity in construction, the project schedule in the contract has to be identified to find out how to fulfill the project completion date.

As it was stated previously in manufacturing aspect, the customer will specify the quantity of the required products on daily, weekly, monthly or yearly basis based on the purchase order which has been placed by him. While in construction, the customer is looking to complete his unique project within specified schedule and budget as stated in the project contract. Thus, in this research, the takt time is defined as the rate at which a pipe joint must be completed to complete the construction of an underground pipeline to satisfy the client requirements.

This difference implied in a new form of calculating takt time for construction, obtained by means of the division of the effectively available time for each stage by the amount of joint to be executed. As a result, takt time of the construction will indicate the time in which a one pipe joint should be completed, stipulated in the contract planning baseline.

For aforementioned case study at the beginning, the project scope is to install **36,500 meters** of the underground pipeline; the pipe size is the 36-inch diameter and shall be completed within 25 months. Based on the above information and as a contingency plan, an internal schedule has been built show the project shall be completed within 23 months. According to project scope, 3,343 joints must be completed.

$$\text{Targeted productivity rate} = \frac{\text{Number of joints}}{\text{Available time}}$$

Available time = 23 months x 26 days = 598 days.

Number of joints = 3,343

Targeted productivity rate $= \frac{3,343}{598}$ = 5.6 joint / day.

As a result, the takt time in construction is defined by a required time to produce one joint which stipulated in the contract.

$\text{Takt time} = \frac{Available\ duty\ time\ per\ day}{poductivity\ rate\ per\ day}$ = $\frac{600\ minutes}{5.6}$ = 107 minutes. (This is the TAKT time required to complete installation of two pipes and one joint).

The below figure 23 shows the process time for each construction stage compares to the Takt time.

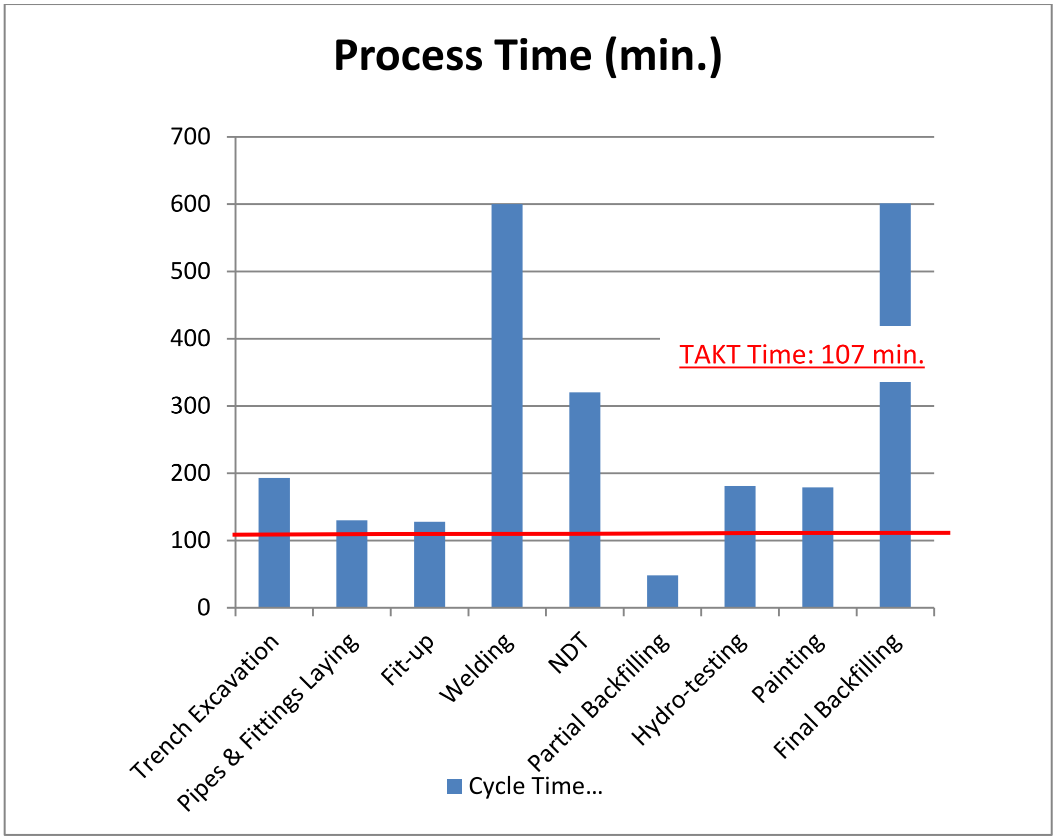

Figure 23. The Process time for each construction stage compare to the takt time

The process time for all entire construction activities is higher than the Takt time. The welding and final backfilling processes are the bottleneck of the entire process; this means that there will be waiting time to complete these activities idle manpower is expected. Thus, the construction activities have to be synchronized to achieve the rhythm of takt time and complete within contract duration.

Therefore, in the future state, a value stream mapping tool will be utilized to improve the construction productivity and reduce the cost by precisely adapting the concept of value stream mapping to the construction activities.

3.2.6 Costing of Current State of Value Stream Mapping

The concept of costing the value stream mapping is introduced in the construction to increase the effectiveness of the process flow and reduce the time wastes during construction.

In this research, a concept was developed to include the cost to the value stream mapping to improve the cost control for construction projects. The cost includes all direct and indirect costs which are relevant to this process and normally it has to be done on a weekly basis to get a clear vision about the total cost for estimation purpose. The same can be a lesson learned for execution of similar projects. Figure 24 illustrates the costs that are related to the calculation of value stream mapping.

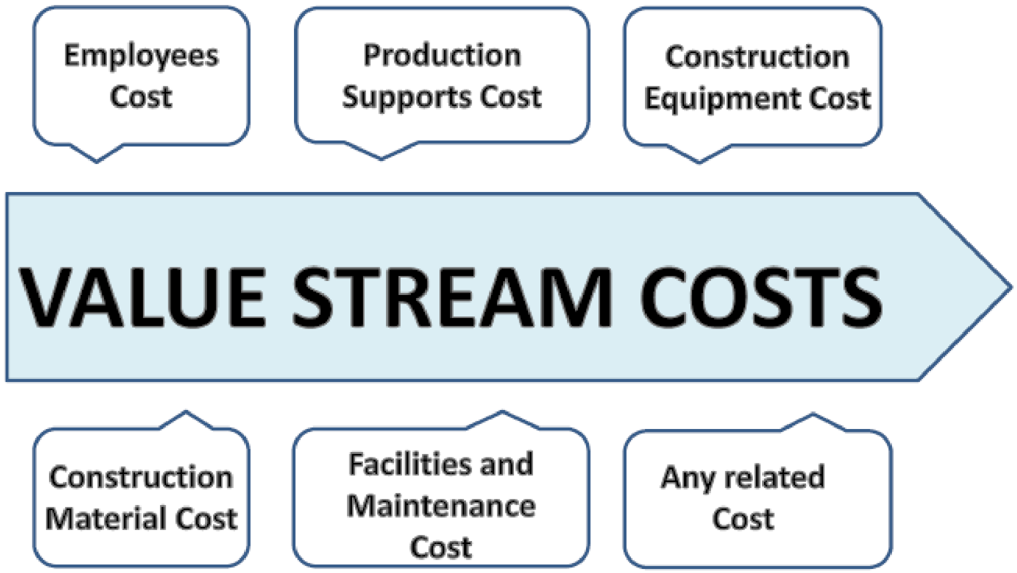

Figure 24. Costs included in cost based VSM

The value stream cost is basically calculated weekly and takes into account of all costs in the value stream mapping. As mentioned previously all costs related to value stream mapping is considered a direct cost. Any cost outside the map is not part of the costing of value stream mapping. Costing of value stream mapping is listed in detail in Appendix G. Table 7 below provides the summary of cost considered for the current state of value stream mapping for a week period. The total cost is $ 19,477 which will be compared with a cost of future state value stream mapping to evaluate and highlight the difference between two costs.

Table 7

Cost of current state activities

Current State of VSM	Employee cost ($)	Production Support cost ($)	Maintenance Cost ($)	Machine/Equipment cost ($)	Other Costs ($)	Total Cost ($)
Trench Excavation	1,306	250	550	1,096		3,202
Pipe & fittings laying	583	286	389	603		1,861
Fit-up	755	250				1,005
Welding	617	500	150	274	300	1,841
NDT		20		350		370
Partial Backfilling	1,062		150	822		2,034
Hydro-testing	754	145	130	250		1,279
Painting	617	250	95			962
Final Backfilling	822	250	255	1,096		2,423
	4,500 (Construction Managers and Site Engineers)					4,500
Total						***19,477***

- Employee cost: the basic salaries and employee benefits.
- Production support cost: Expenses are not directly associated with construction activities such as design, engineering, and procurement.
- Maintenance cost: cost incurs to keep equipment or machine in good working condition.
- Machine/Equipment cost: In this research, it is incurred in the rental cost and operating cost.

- Another cost: Cost-based value stream mapping is considered direct cost, while the cost outside of the value stream is not included in the value stream cost.

3.2.7 Integration of VSM and LOB

This research proposes a model to optimize resource usage, including time and labor, through VSM improvement techniques. Moreover, the work was developed by a literature review of intrinsic concepts both on lean philosophy and line of balance programming technique. The characteristics of lean thinking can be applied to initial sketches of a line of balance. The first activity defines a production rate (takt time), in order to synchrony and parallelism between construction activities. Then, minimization of production and transfer batches was conducted by leveling the required joints. In drawing LOB, repeatability of cycles is a parameter that comes naturally. This repetition occurs according to four phases: planning, doing, checking and acting. Checking might tell that goal are not being met; acting (reacting) will provide the managerial mechanisms to allow continuous improvement in the next cycles.

Production leveling is obtained by reducing the cycle time, visualizing activities to be performed in a given space and time makes it is possible to indicate which activities shall be pulled by their successor ones. The use of Kanban is the answer of VSM to pull production: line of balance allows understanding how kanban works on a construction site. Pull production allows the minimization of inventory, once the process is viewed as a whole, knowing the exact moment that resources will be used. Thus, LOB is a variation of linear scheduling methods that allows the balancing of operations such that each activity is continuously performed. Its major benefit is that it provides production rates and duration information in the form of an easy to interpret graphics format. The sequence of activities in LOB enables the choice of how best to avoid overlapping of activities. Knowing the rate and sequence of activities for each operator is possible to establish synchrony and identify any delaying activity (bottleneck) as shown in tables 4 and 5.

The construction industry has a different production problem as compared to the remaining manufacturing enterprises in the sense that there is a flow of workers and not of products through an assembly line. Thus, through the line of balance, it is possible to identify different production-like cells working in parallel and in small batches, obeying the same rate and sequence of activities. By production-like cell is meant the fact that each activity looks like being carried out by specialists, but there is no hindrance to making workers tackle different activities in close-by repeating units. Advantages of parallel production and cell are the elimination of peaks and valleys of consumption of resources, teamwork, focused layout, more control and decreased transport distances. Moreover, when two or more activities occupy the same space and are performed at the same time, it is claimed that interference of tasks can be harmful to production. LOB helps to visualize the occurrence of interference activities and thus preventing them from occurring, anticipating problems that are commonly detected only during work execution.

All the above LOB basic concepts are implemented in suggested improvement to develop the required resources according to the future state of VSM and to identify its potential relationship as a planning technique to the principles of Lean Construction. It takes the latter theoretical concepts into practical graphical easy to understand applications.

CHAPTER 4
SUGGESTED IMPROVEMENT AND FORMULATION FOR THE FUTURE STATE OF VSM

The value stream of the current state was formulated in the previous chapter. The desired productivity was also defined previously. In this chapter, the future state of value stream mapping and process elements will be analyzed considering the calculated desired capacity and takt time to reduce the process time and increase the efficiency. Accordingly, the following improvements were proposed to build a future state value stream mapping.

4.1 Suggested Improvements

The following suggested improvements were developed according to the construction status in guidance with the implementation of the modified basic concept of value stream mapping.

a) Pull system and synchronize first-in, first outflow:

Trench Excavation, partial and final backfilling: the process time for each activity is higher than takt time. The required improvement is to reduce the non-value added especially the waiting time which is required to prepare the trench, bedding, and inspection prior to place and laying the pipes. The excavation is the first construction activity. Thus we assigned an excavation team to start the excavation activity earlier one hour in advance which provides enough time for next activity to start earlier and reduce the waiting time. Moreover, we proposed to introduce a continuous flow and develop an open work front by eliminating the partial backfilling activity. The agreement between the main contractor and consultant was developed to proceed with painting and coating after completion of NDT test. Then, the pipeline will be backfilled finally to be ready for the final test. Although, high risk for the contractor, significant suggestion to improve the productivity. The excavation team as one crew of 10 persons under one supervisor for excavation and final backfilling. In value stream mapping, we call it first in/first out or pull system, where a downstream is pull the upstream activity to improve the workflow and improve the utilization of manpower and equipment. Thus, 24 hours was given to backfilling team to complete the final backfilling after completion of five joints. The application of continuous flow, the non-value added time for trench excavation, partial backfilling and final backfilling has been reduced.

b) Combined and restructure the work activities (fit-up and welding activities):

As stated in the current state of value stream mapping, the takt time and production rate are difficult to achieve since the time required to complete the installation of one joint is 107 minutes. Welding activity has high process time, therefore and in coordination with the engineering, a technique called Weld Map Drawing was initiated.

Basically, welding map is an isometric drawing shows the location of all pipe joints in the project, as shown in the below figure 25.

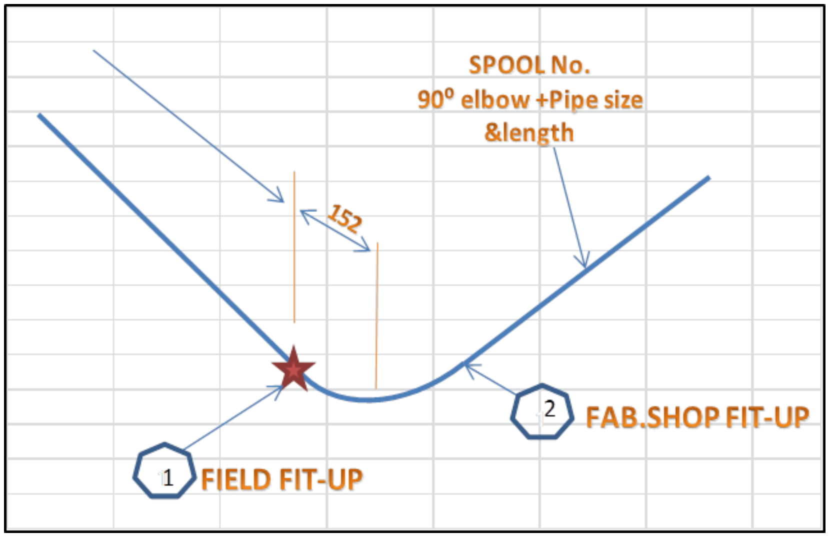

Figure 25. Sample of Weld Map

Immediately, after finalizing the construction drawings, project engineering section will commence with generating weld map drawings, each one shall show the welding status for each joint in accordance with field weld or at manufacturer shop. Normally, the engineering section in coordination with construction field will study and investigate thoroughly in detail each joint and specify the joint status with respect to field weld or manufacturer joint weld, which call it a “SPOOL” Figure 26. After finalizing the list, the spools required date schedule will be generated and submitted by construction team to the manufacturer, this allows construction and spool manufacturer to track and expedite the spool fabrication until completion date.

Figure 26. SPOOL shows shop weld and field weld

By weld map drawing and spool concept, the welding process time will be reduced accordingly. To speed up the welding process, the construction team may ask the engineering to generate a list of tack welding spools as shown below in figure 27

Figure 27. Sample of tack weld spools

Welding map concept is an effective technique and plays a vital role in enhancing and speed up the productivity in the construction of the pipeline. In this study, the joints that can be fabricated in the shop by the manufacturer are 1171 joints, and the construction team suggested to reduce the idle time of the workers by merging the group of fit-up and welding teams for their identical task. The pipefitters were subject to tack welding training for two weeks period which enhances the productivity of welding process. Thus, the total joints shall be welded at the site are 2172 joints.

The implication for the above strategy was significant. The observation for welding activity cycle time is reduced and the process time is reduced as well.

c) Production leveling by pacemaker/supermarket:

Welding and NDT activities: These activities in value stream mapping where continuous flow is not applicable and batching is necessary. According to value stream mapping, we introduce the concept of Supermarket Pull System between welding process and NDT process.

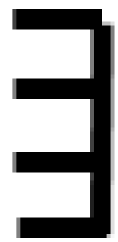

Figure 28. Supermarket system symbol

Basically, the supermarket pull system is a controlled inventory of joints that are subject to testing schedule in due course according to site situation. Therefore, the joints were accumulated to perform NDT test in one shot. Moreover, the NDT was scheduled to be during the night to perform more tests without any interruption. According to project baseline schedule, the takt time was scheduled to produce 5 joints per day to meet the project completion date. The completion date was scheduled two months ahead, as a safety factor. The proposal was introduced to prepare 5 joints for the test which facilitate an open front for other activities and optimize the resources effectively.

The value stream mapping deals with the entire system as one production, not the individual. Therefore, the implementation of value stream mapping will be in steps and divided into loops. The concept of pacemaker loop encompasses the flow of information and material between the main construction and testing. The downstream loop is impacted by the upstream loop, and this can't be done without proper scheduling and continuous development.

d) Work restructuring to improve the construction reliability:

Hydro-testing was scheduled after completing the NDT test, painting and final backfilling, which was in coordination and approval of Project Resident Engineer. To ensure a proper stability and anchorage for the network integrity, the final backfilling has taken place prior to proceeding with Hydro-test. This was suggested to apply the concept of Supermarket Pull system and to ensure a continuous flow. This can be achieved by a batch of Kanban (It is Japanese term indicate to flushing device that gives authorization and instructions for the production or withdrawal conveyance of items in a pull system) by preparing a minimum of 5 completed welded joints for NDT test and build a ready pipeline for hydro-test according to site condition. By this improvement, we minimize the required number to perform the hydro-testing activity and produce more productivity.

e) Painting:

The process time of the painting process is higher than takt time. Thus, the wastes and waiting time have to be minimized. Due to the supermarket concept which was introduced and developed between welding and NDT activities, the continuous flow is generated to catch-up the quantity of joint generated after hydro-testing.

f) Manpower leveling and LOB:

As illustrated in section 3.2.7, ntegration of LOB with VSM played a vital role in leveling the required manpower. In this study, the resource leveling was achieved by identifying the number of crews w required to complete the project on time. Uses velocity rating diagram to find required resources for each stage so each work stage can be done by the synchronized crew and continue without interruption. According to LOB technique, the following steps were applied:

- The improvement was implemented to draw the production rate according to takt time. Vertical axis plots the cumulative progress of a number of joints completed in the project. Horizontal axis plots time and sloping lines represent the rate of production, i.e., number of joints per day.
- The LOB implemented after reduction of the cycle and lead times, thus based on the 23 months required to complete the project , the crews are distributed as follows:
    a) Two crews for excavation and final backfilling. Each crew consists three civil workers under one supervisor.
    b) One crew ofe pipes and fittings laying (three pipe fitters)
    c) One crew for fit-up and welding (four welders and three helpers)
    d) One crew for NDT testing (two NDT technicians)
    e) One crew for painting (three painters)
    f) One crew for Hydro-testing (four mechanical/pipe fitters).

The repetitive activities are distributed uniformly to ensure a proper utilization of manpower and tools, as in figure 29.

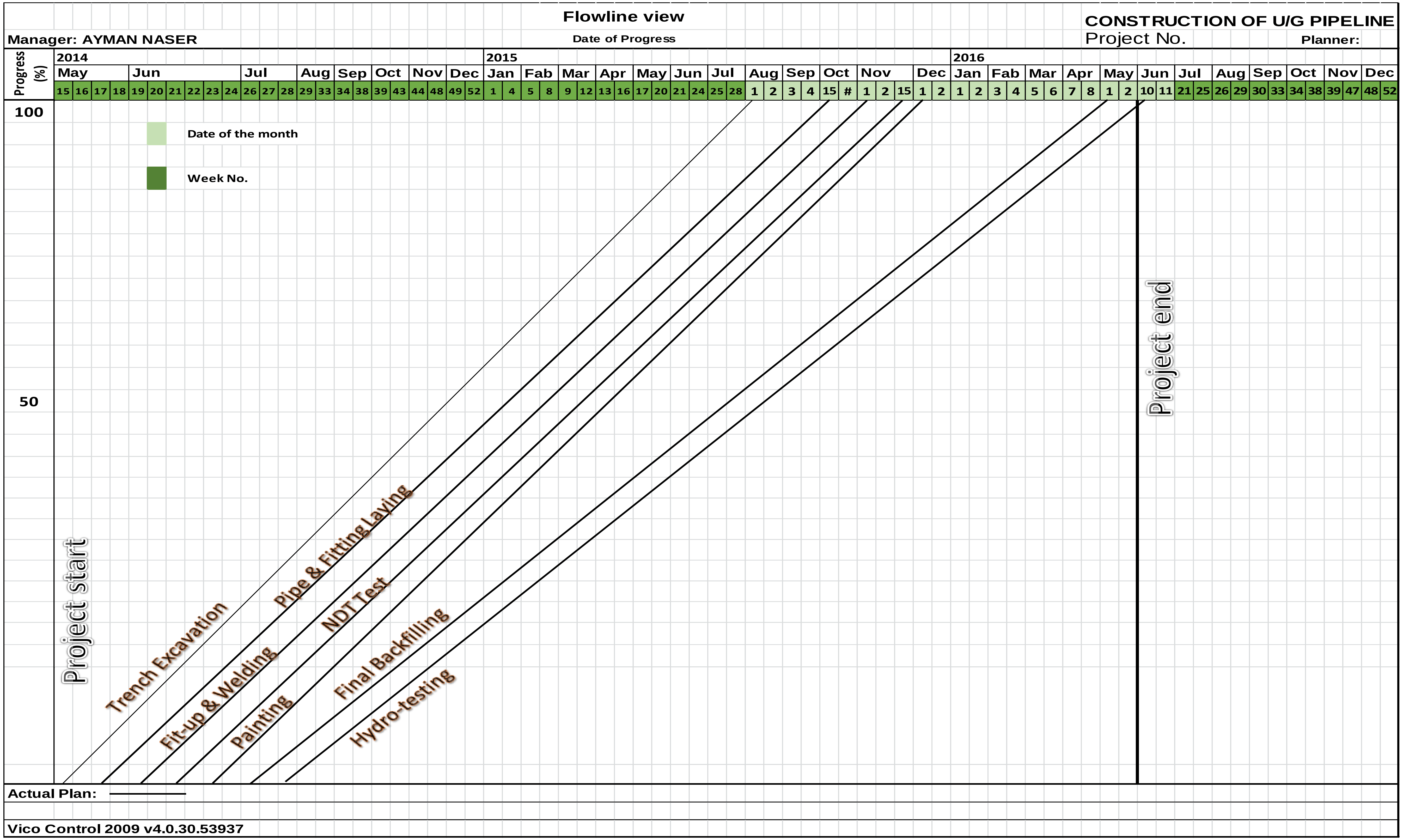

Figure 29. LOB for manpower leveling

4.2 Proposed Future State of Value Stream Mapping

The previously mentioned improvements were implemented in the current state to achieve the future state as illustrated below in figure 30.

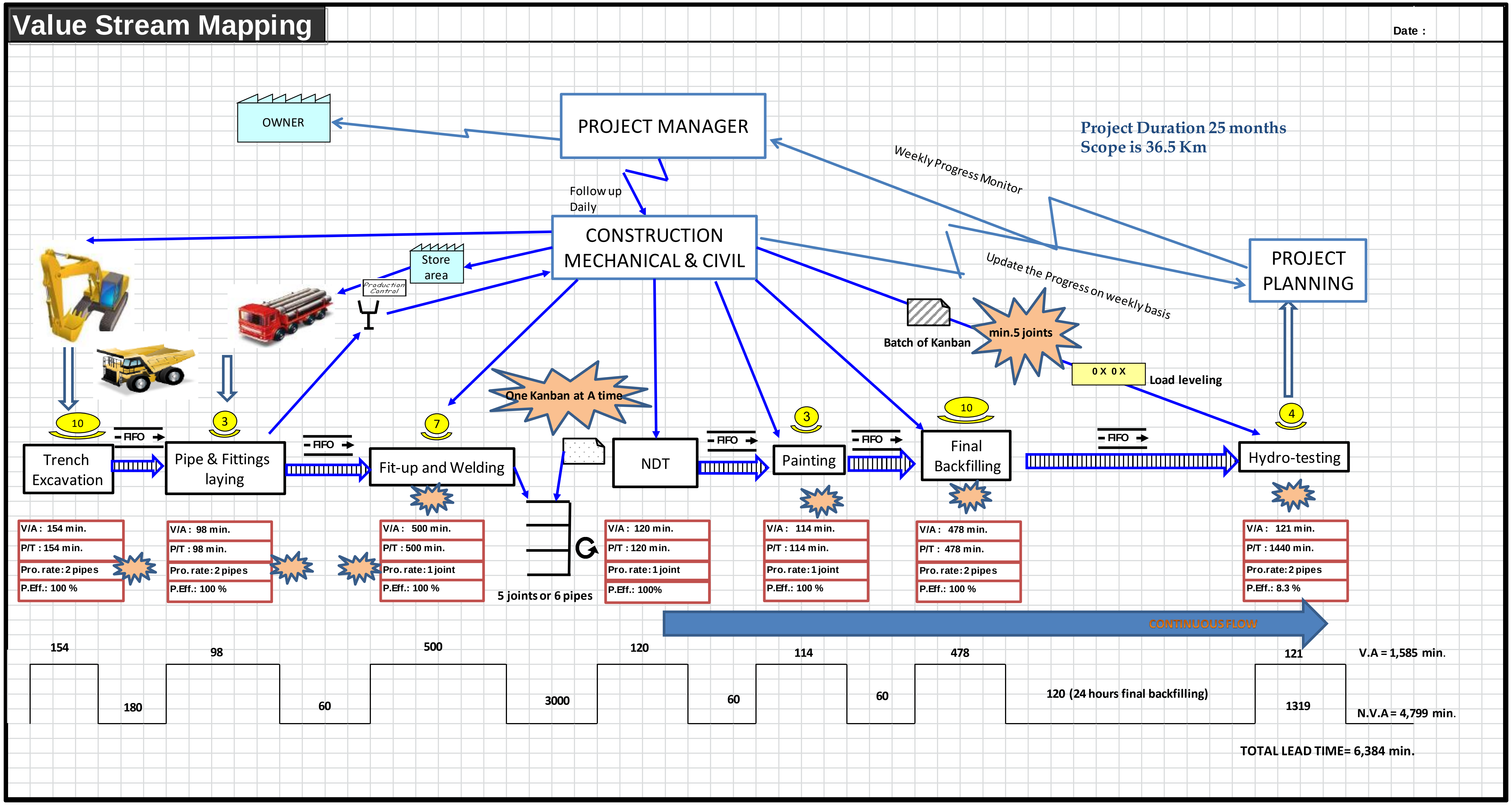

Figure 30. Future state of VSM for construction of underground pipeline

The symbols and icons for current and future states of VSM are illustrated in Appendix B

The future state of VSM shows an impressive improvement in the construction process. Obviously with a reduction of total lead time, reduction in the time wastes (NVA) and increase in value added time (VA) with respect to the lead process time. Table 8 shows the improvements were achieved:

Table 8

Production capacity comparison between current state and the future state of VSM

Construction Activity	Current State	Future State	Improvement
Lead Time (min.)	8,545	6,384	25.3 %
Non-Value added (min.)	6,953	4,799	30.9 %
Production capacity	1 joint / 2 pipes	1 joint/ 2pipes	

- The lead time was calculated in current state **8,545** minutes based on the construction of one joint. While the total lead time in the future state is 6**,384** minutes. There is an improvement of **25.3 %.**
- The percentage of value-added time in the current state with respect to the lead time is 18.6 %, and it is improved by 2**4.8 %.**
- With the application of VSM, the non-value added time is reduced by **30.9 %**. The

NVA was **6,953** minutes and reduced to **4,799** minutes.

- The comparison of production capacity for current and future states is based on one joint and two pipes for current state and the future state of VSM.

As a result, future state map has to be validated on continuous improvement basis. Takt time for the construction can be calculated based on the customer's requirement and according to the signed contract between the parties. Thus, each process possesses different takt time to be executed and calculated accordingly.

Therefore, takt time shall be developed by establishing a pull system, introduce a leveling system, and establish a pacemaker loop as shown in below indicative figure 31 for the future state of VSM.

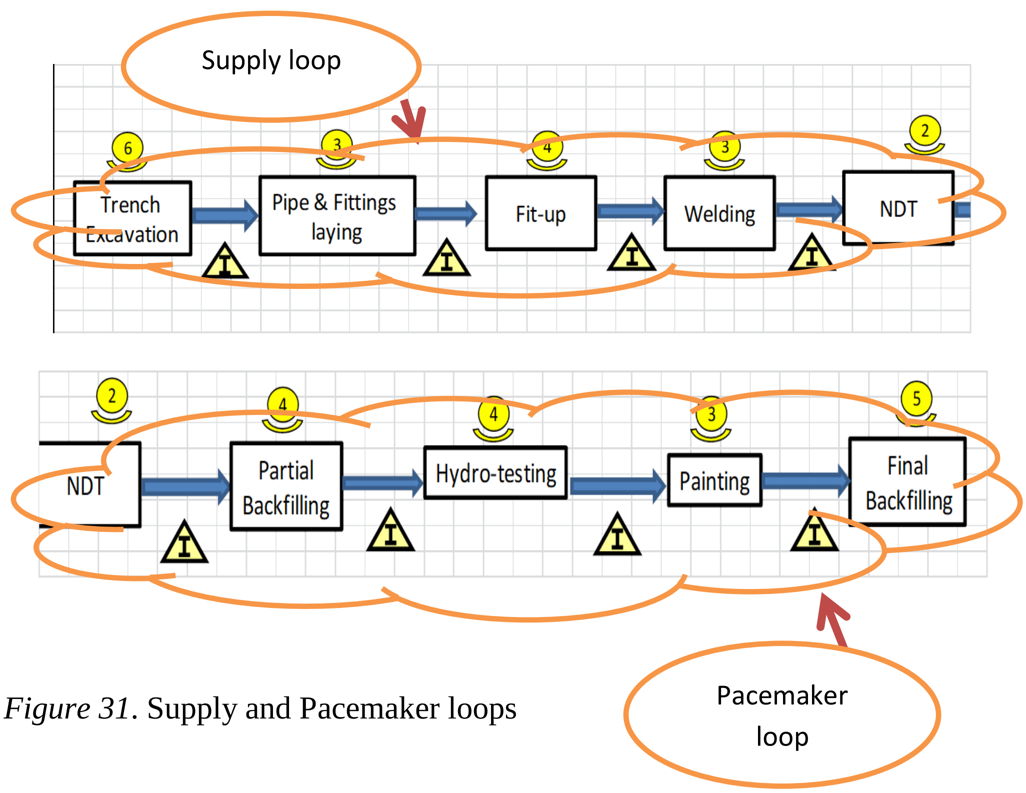

Figure 31. Supply and Pacemaker loops

The takt time for supply and pacemaker loops was developed to meet the contract completion date. The time for supply loop is 992 minutes and the required time to complete the pacemaker loop is 2,392 minutes with a controlled inventory of supermarket time of 3,000 minutes. The construction capacity was adjusted to construct of five joints and six pipes. Thus, the takt time for each process loop was balanced to the rhythm in order to meet the project completion date accordingly.

The major benefits of the loops are to develop a continuous flow which can be utilized to construct the pipeline based on the loop takt time. Establish a pull system between the loops to control the construction activities. Level the resources utilization based on a combination of VSM with LOB tool to minimize the cost.

4.3 Costing of Future State of Value Stream Mapping

Costing of a future state was calculated as in the current state of value stream mapping to evaluate the importance of total cost reduction by utilizing the value stream mapping in the construction. After suggestion improvements and the formulation of the future state of value stream mapping, the cost has been calculated based on the rates as mentioned in the Appendix - E and summarized in table 9 of the weekly period as implemented in the current state.

Table 9

Cost of Future state activities

Future State of VSM	Employee cost ($)	Production Support cost ($)	Maintenance Cost ($)	Machine/Equipment cost ($)	Other Costs ($)	Total Cost ($)
Trench Excavation	1,424.7	250	550	310.5		2,535.2
Pipe & fittings laying	602.7	286	389	125.4		1,403.1
Fit-up Welding	1,095.9	500	150	82.2	300	2128.1
NDT		20		350		370
Partial Backfilling						
Hydro-testing	754	145	130	250		1,279
Painting	617	250	95			962
Final Backfilling	1424.7	250	255	310.5		2,240.2
	4,500 (Construction Managers and Site Engineers)					4,500
Total						***15,417.6***

The calculation was for costs allocated to the value stream only. VSM is constructed to provide precise, understandable and relevant cost information for estimator and project manager.

In comparison between the cost-based on current and future states of value stream mapping as illustrated in table 10, the reduction is 20.8%. It shows the importance of utilizing the value stream mapping in construction as a management tool. It can be utilized to evaluate the construction status and show where the construction is standing on. Moreover, this technique provides an accurate cost calculation can be used for tendering purpose in future.

Table 10

Cost based VSM comparison between current and future states

VSM State	Cost
Current State	$ 19,477
Future State	$ 15,417.6
Cost reduction percentage between current and future states	20.8 %

CHAPTER 5

DISCUSSION OF RESULTS

The objective of this study is to enhance and develop the utilization of VSM as a lean management tool in the construction industry and emphasize the VSM benefits by adopting to a cost-based performance measurement.

This research has emphasized on developing a steady production flow and eliminating the entire process waste. It is a powerful lean construction tool, was used to analyze the construction process and restructure the production system. Moreover, compared to manufacturing, the construction of underground pipeline poses some special particularities, making the direct application of VSM very difficult. This paper has proposed a practical approach to utilizing VSM in a construction setting.

By being the part of the construction industry with the ability to bring in cost and productivity advantages, a value stream mapping stands as a more attractive alternative when compared with the other conventional management tools. To capitalize on such benefits, the followings were observed as remarkable improvements:

- After analyzing the implementation of value stream mapping in the construction industry and demonstrate the physical application by using a real case study, the improvement that has been noticed during application of VSM in the construction industry reflect the importance of value stream mapping as a lean management tool in the whole of construction life cycle.

- In term of Lead time, the improvement for the construction stage is tabulated comparing the current state and the future state of the value stream as illustrated in table 11 and figure 32 below.

Table 11

Construction stages Process and NVA time improvement

Construction Process	Current State L/T (Minutes).	Future State L/T (Minutes).	Improvement (%).
Lead time	8545	6384	25.3
NVA	6953	4799	30.9

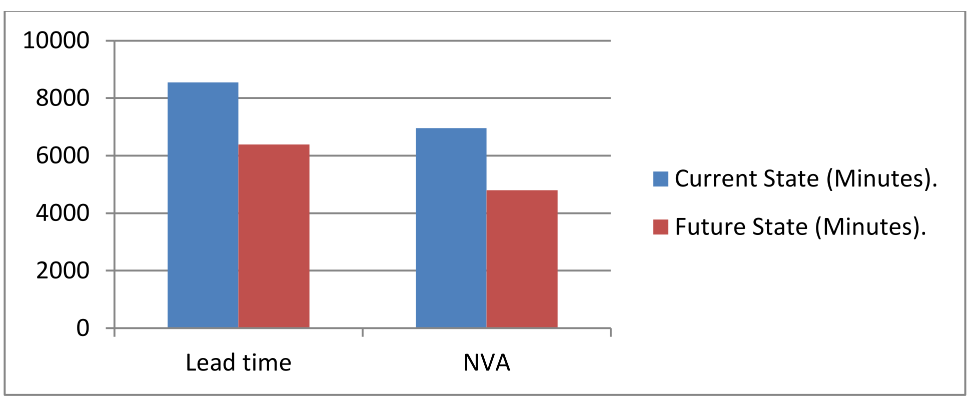

Figure 32. PT and NVA improvement in comparison between current and future states

- In term of non-value added time (NVAT), the reduction for the construction stage is tabulated comparing the current state and the future state of the value stream as illustrated in table 12 and figure 33 below.

Table 12

Comparison stages reduction of NVAT

Construction Stage	Current State NVAT (Minutes).	Future State NVAT (Minutes).	Improvement Percentage (%).
Trench Excavation	60	0	100
Waiting for next activity	780	180	76.9
Laying Pipes & Fittings	32	0	100
Waiting for next activity	90	60	33.3
Fit-up	38	0	100
Waiting for next activity	80	0	100
Welding	90	0	100
Waiting for next activity	3000	3000	0
NDT Test	120	0	100
Waiting for next activity	200	120	40
Partial Backfilling	0	0	0
Waiting for next activity	80	0	100
Hydro-testing	60	1319	12
Waiting for next activity	1440		
Painting	40	0	100
Waiting for next activity	720	120	80.6
Final Backfilling	123	0	100
Total VAT	6953	4799	30.9

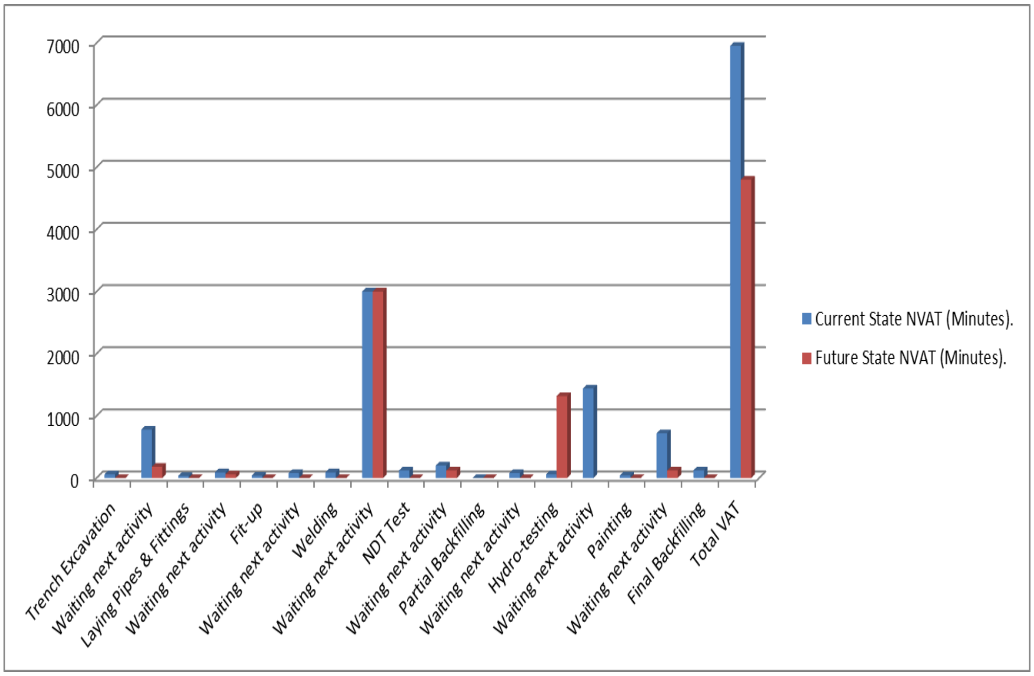

Figure 33. NVAT reduction in comparison between current and future states

Tables 11 and 12 and figures 31 and 32 show the importance of VSM as a lean tool in the construction of the underground pipeline; the Lead time was improved by 25.3 %. While the NVAT was reduced by 30.9 %

- Obviously, to evaluate the utilization in the construction industry, the VAT was compared to process time for each construction stage. Consequently, the construction can be improved based on the concept of takt time which shall be measured by the percentage of VAT in the process time for each construction stage as shown in table 13 and figure 34.

Table 13

Comparison between VAT to process time in current and future states

Construction Stage	Current State VAT (Minutes).	Current State Process time (Minutes).	Percentage of VAT compared with process time in Current state (%)	Future State VAT (Minutes).	Future State process time (Minutes).	Percentage of VAT compared with process time in Future state (%)
Trench Excavation	133	193	68.9	154	154	100
Laying Pipes & Fittings	98	130	75.4	98	98	100
Fit-up	90	128	70.3			100.0
Welding	510	600	85.0	500	500	100
NDT Test	0	320	0.0	120	120	100
Partial backfilling (P)	48	48	100.0	1440(P+F)	1440	100.0
Hydro-testing	121	1561	7.8	121	1440	8.4
Painting	114	834	13.7	114	114	100
Final backfilling (F)	478	601	79.5	1440(P+F)	1440	100.0

- Thus, to evaluate the utilization in the construction industry, the VAT was compared to process time for each construction stage. As mentioned the construction can be improved based on the concept of takt time which shall be measured by the percentage of VAT in the process time for each construction stage as shown in figure 34.

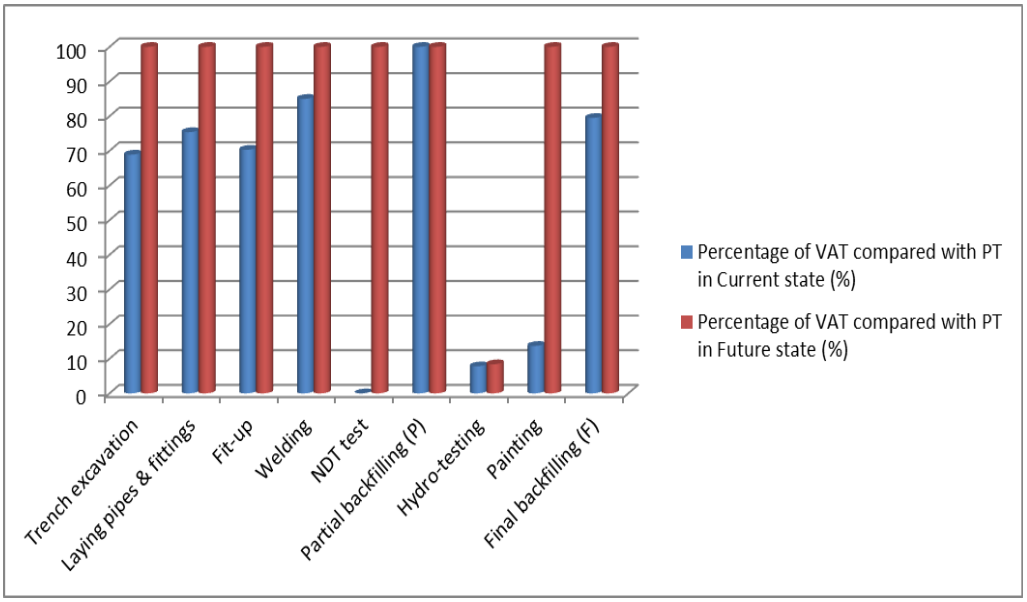

Figure 34. Percentage of VAT to process time in comparison between current and future states

- The major benefit of integration of LOB tool with VSM is to optimize the resources utilization. Table 14 shows the required manpower for current and future states based on VSM-LOB tool.

Table 14

Manpower requirement for current and future states

Serial No.	Trade	Current State	Future State
1	Project Manager	1	1
2	Construction Manager - Civil	1	1
3	Construction Manager - Mechanical	1	1
4	Site Engineer	3	3
5	Supervisor - Mechanical	2	1
6	Supervisor - Civil	2	1
7	Supervisor - Painting	1	1
8	Supervisor - Welding	1	1
9	Operator	7	7
10	Civil Worker	10	6
11	Pipefitter	8	7
12	Welder	2	4
13	Helper	4	3
14	Painter	3	3
15	NDT technician	2	2
	Total	48	42

- In term of cost of value Stream mapping as shown in table 15, the implementation of the costing concept as discussed in the construction industry has played a vital role in evaluating the cost reduction and estimates a similar construction activity. The cost is reduced by 20.8 % in the comparison between two VSM states.

CHAPTER 6
CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

6.1 Summary and Concluding Remarks

This study plans to develop a better understanding of VSM, and it modified, introduced additional tactic, i.e., LOB and applied VSM for a real construction project. Moreover, it developed a concept to calculate the cost of value stream mapping on a weekly basis. This technique can be utilized to understand the construction progress status and the future expectation of the status. Moreover, it can be based on a reference to calculate the cost of similar projects for bidding purpose.

With the assistance of value stream mapping concept and tools, the time wastes can be identified in each stage and can be modified by VSM to enhance the construction process according to site condition to reduce the wastes and cost in the construction industry.

This study attempted to highlight the implementation of value stream mapping to a real-life problem based on case construction study (construction of underground pipeline). It analyzed the improvement of VAT and reduction of NVAT. It studied the reduction opportunity in total lead time that resulted in high benefits. LOB tool with VSM as a new tool provided a powerful attempt for proper resources utilization and monitoring.

The cost was designed to provide relevant, accurate and understandable cost information for project managers. In this study, one can see how operational improvements in flow manpower resources, VAT, VAT and lead time go hand in hand with the cost of the value stream. As the process becomes more stable less work-in-process, better balance, shorter lead times, and the cost per part decreases. There is a positive correlation between lean practices and financial parameters.

Although several papers address using VSM as a lean tool to reduce waste and add value during the construction process, no detailed and unified VSM instructions exist concerning how to implement it in construction. This study applied cost component and LOB techniques to better analyze the construction project.

With the increase of competition and the complexity of construction process, conventional VSM is not sufficient as a lean tool to identify waste and non-value activities. Therefore, cost based on the value stream mapping offer promising trends for using value stream mapping in the construction and deserves more attention on it. The implementation of these proposed improvements would result to meet the completion project date.

6.2 Research Contributions

The three integrated models (LOB, VSM, and Cost based VSM) of the developed methodology provide flexible and comprehensive tools for optimized scheduling of repetitive construction projects under cost monitoring technique. During the research and as the methodology was being developed, several original contributions have been made:

- Developed optimized scheduling and costing model capable of optimizing schedules for least project duration or least total project cost, while offering users enough flexibility to model uncertainties in different input parameters.
- Developed LOB with VSM approach that provides a systematic tool for building a required manpower to protect the project schedule against anticipated delays. The resource sizing introduces the utilization of the agreement index factor (AI) to build buffers in order to meet project's desired confidence level in the generated schedule.
- Developed dynamic rescheduling model that capitalizes on the repetitive nature of the project. Through the utilization of onsite data capturing, this model adjusts cost estimates for the remaining part of the project.
- Developed a schedule acceleration model that capable of finding least-cost acceleration plans through accelerating activities.
- By fulfilling the objectives, this study contributes to filling a gap in research using a Value Stream Map to analyze a process, based on cost rather than time only, especially when describing this in the construction of the underground pipeline. Due to the purpose of a case study making findings generalizable, the methodology has the potential to be applied to other construction activities.
- Integration of LOB and VSM provides:
    - Clearly shows the amount of work taking place in a certain area at a specific time of the project.
    - Has the ability to show and optimize the resources used for a large

number of repeated activities, executed in several zones or locations.

- Easier cost and time optimization analysis because of all the information available for each activity in the project.
- Ease of setup and its superior presentation and visualization.
- Easier to modify, update and change the schedule.
- Better managing of all the various sub-contractors in the project.
- Allows for simpler and clearer resource management and resource optimization functions.
- Visualization of productivity and location of crews.
- It allows project managers to see, whether they can meet the schedule if they continue working as they have been.
- Different cultural aspects surfaced regarding the adoption of cost-based concept and presentation of LOB for the purpose of easy understanding is convenient

6.3 Future Works

Future research can be extended and focused further on the following:

- Apply value stream mapping for other repetitive and non-repetitive construction activities.
- Integrate and combine VSM with other tactics and lean management tools to improve the benefits of value stream mapping in the construction industry.

- Incorporate and evaluate the cost based VSM for bidding and estimation purpose.
- In an academic context, there is some potential for future research in applying the VSM and cost analysis in other industries to assess the adaptability and usefulness of the Value Stream Map developed. The symbols for cost-based VSM can be developed further.
- There is also a potential research avenue to integrate a traditional VSM analysis with the cost-based VSM developed in order to conduct a two-pronged analysis of both time and cost.
- Using discrete event simulation in the case of the availability of relevant historical data could be a more objective approach.

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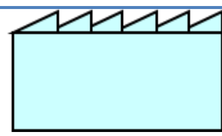
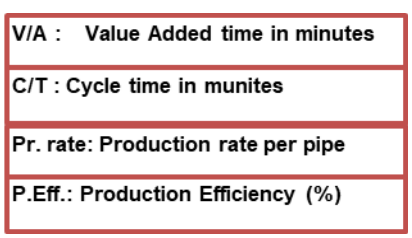
APPENDICES

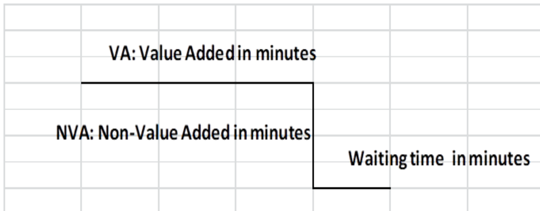
Appendix A: Observation of current state for construction of underground pipeline network

Observation Trial no.	Value Added (VA) and Non Value Added (NVA)	Trench Excavation(2 pipes)	Pipes & Fittings Laying (2 pipes)	Fit-up (one joint)	Welding (one joint)	NDT Test (five joints)	Partial B.F (one pipe)	Hydro-testing (five joints)	Painting (one joint)	Final B.F (one pipe and joint)
Observation-1	VA	125								
	NVA	60								
Observation-2	VA	130	94	83	540					
	NVA	60	30	40	60					
Observation-3	VA	125	100	90	530					
	NVA	60	30	30	70					
Observation-4	VA	135	110	95	500		45			
	NVA	60	25	35	100		0			
Observation-5	VA	129	122	95	530		45			
	NVA	60	22	30	70		0			
Observation-6	VA	154	89	95	500		40	120	100	
	NVA	60	25	30	100	120	0	1440	720	
Observation-7	VA	113	95	88	550		44		100	480
	NVA	60	33	35	50		0		720	120
Observation-8	VA	125	95	86	450		55		110	500
	NVA	60	30	36	150		0		720	100
Observation-9	VA	136	90	88	490		52		125	455
	NVA	60	30	45	110		0		720	145
Observation-10	VA	155	85	88	499		53	122	135	475
	NVA	60	30	60	101	120	0	1440	720	125
Average Value Added (VA)		133	98	90	510		48	121	114	478
Average Non-Value Added (NVA)		60	32	38	90	120	0	1440	720	123

Appendix B: The Symbols and Icons of Value Stream Mapping in the current and future states.

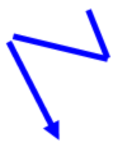
According to Mike Rother, John Shook, Jim Womack & Dan Jones. (2003).

Symbol / Icon	Meaning and Description
	Customer/Supplier Icon: represents the Supplier when in the upper left, customer when in the upper right, the usual endpoint for material
	Manpower Icon represents skilled manpower. Shows the number of manpower required to process the VSM family at a particular workstation
	Dedicated Activity flow Icon: a process, operation, machine or department, through which material flows. Represents one department with a continuous, internal fixed flow.
	Data Box Icon: it goes under other icons that have significant information/data required for analyzing and observing the system.



Timeline Icon: shows value added times (Cycle Times) and non-value added (wait) times. Use this to calculate Lead Time and Total Cycle Time.

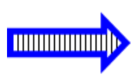
Inventory Icons: show inventory and waiting time between two activities/processes.



Electronic Info Icon: represents electronic flow such as electronic data interchange, the Internet, indicate the frequency of information/data interchange.

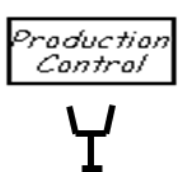
Manual Information Icon: A straight, thin arrow shows the general flow of information from memos, reports, or conversation. Frequency and other notes may be relevant.

FIFO Lane Icon: First-In-First-Out inventory. Use this icon when processes are connected with a FIFO system that limits input.



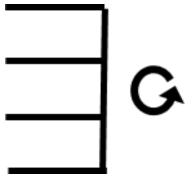
Push Arrow Icon: represents the "pushing" of material from one activity to the next activity.

Kaizen Burst Icon: used to highlight improvement needs and plan kaizen workshops at specific activities that are critical to achieving the Future State Map of the value stream.



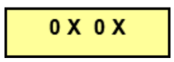
Kanban Post Icon: a location where kanban signals reside for pickup. Often used by a central production scheduling or control production department.

Withdrawal Kanban Icon: represents a device that instructs a material handler to transfer parts from a supermarket to the receiving process. He goes to the supermarket and withdraws the necessary items.



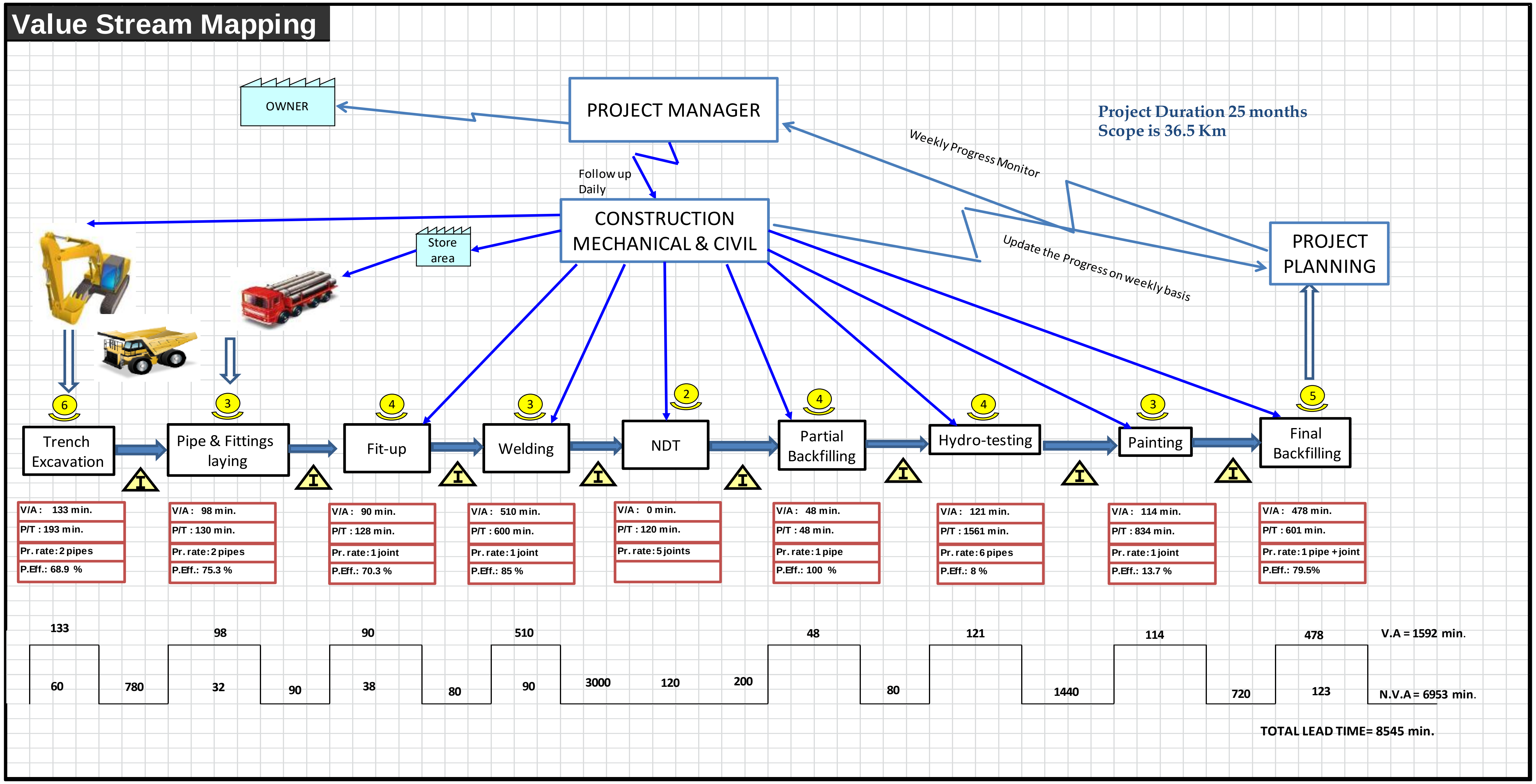
Supermarket Icon: an inventory "supermarket" (kanban stock point) with a"Pull" icon that indicates physical removal.

Production Kanban Icon: triggers production of a predefined number of parts. Signals a supplying process to provide parts to a downstream process.

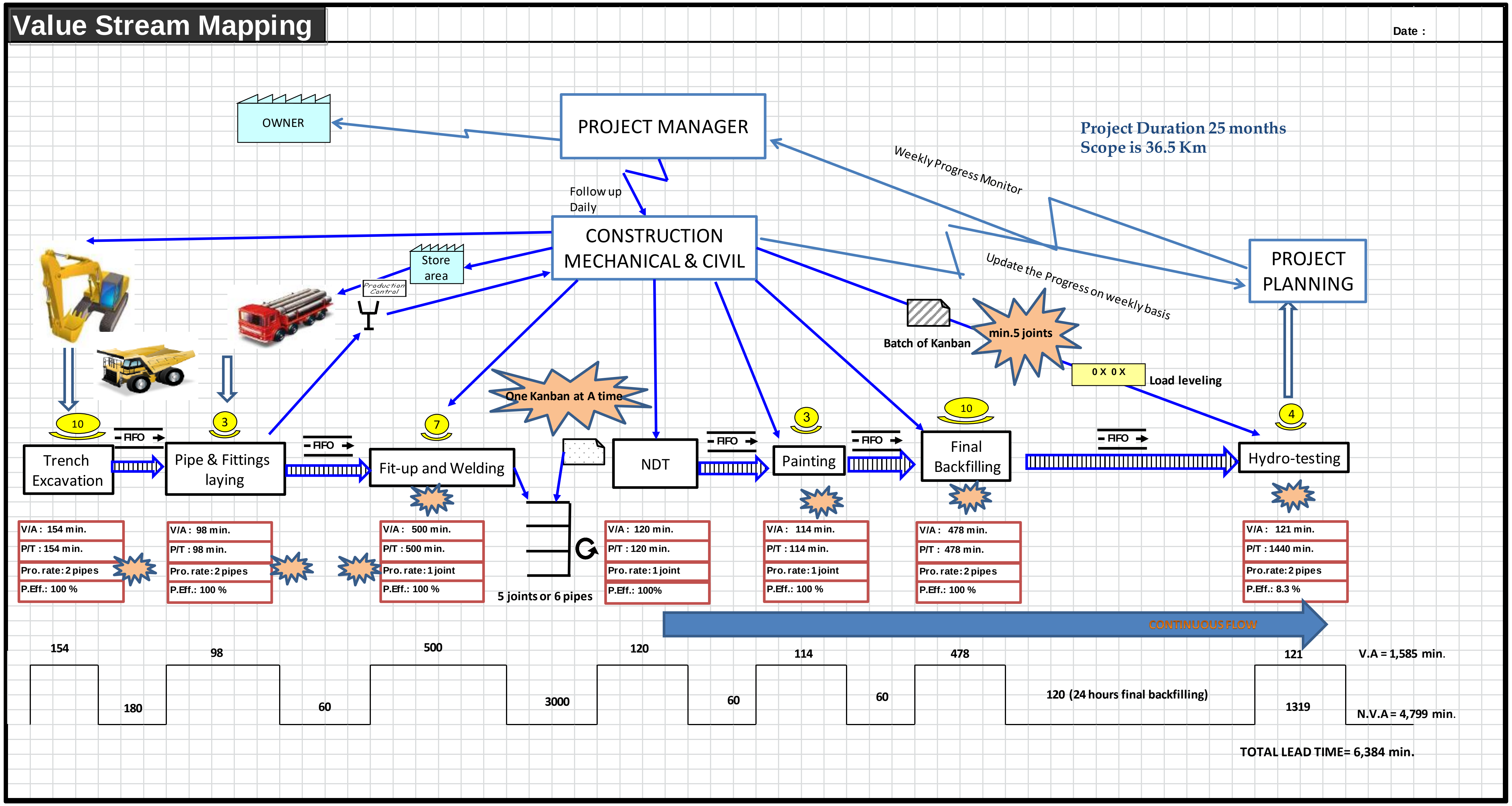


Load Leveling Icon: a tool to batch kanbans in order to level the production volume and mix over a period of time.

Appendix C: Current State Value Stream Mapping



Appendix D: Future State Value Stream Mapping



Appendix E: Manpower and Equipment rates

- Equipment Rates

Construction Equipment	Rate ($)
Excavator	548/ week
Truck (14 Ton)	274/ week
Crane	329/ week
Diesel Welding machine	137/ week
NDT machine “Hiring basis”	205/ 24 hours
Hydro-testing machine	96/ week

- Manpower Rates

Construction Manpower	Rate ($) on monthly basis
Operator	822
Civil Worker	685
Pipe Fitter	685
Supervisor	960
Helper	548
Welder	960
Painter	685