Value Stream Mapping as a Lean Tool for Construction Projects

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***Abstract* — Based on lean thinking which developed from the Toyota industry, seek to wastes elimination, increase the value added to the product from customer point of view and reduce lead time are the main contributes in manufacturing industrial environment. Some adaptations have been applied in construction industry by using a Value Stream Mapping as a lean construction tool. VSM was adapted to reduce the high percentage of non-value-added activities and time wastes during each construction stage. Moreover, a cost estimation model was developed during current state and future state to calculate the cost of underground pipeline construction. Therefore, this paper aims to propose improvements in the construction industry process using Value Stream Mapping. Therefore, the research methodology adopted was the illustrative case study. The results suggest that the construction of underground pipelines process lead time could be potentially reduced by 30.7 % and cost reduction of 20.8 % between current and future states.**

***Index Terms*—Value Stream Mapping (VSM), Line of Balance (LOB), Lean Construction, underground pipeline project, Cost of Value Stream Mapping**

I. Introduction

The construction industry is increasingly moving towards the adoption of sustainable strategies and increased efficiency targets ([1], [2], [3], [4], [5], [6], [7], [8]).

Value Stream Mapping has been utilized in many businesses that to maintain their competitiveness in a booming worldwide market. Value Stream Mapping is designed to eliminate all activities that do not add value throughout the production process [2], [3], [4], [5], [6], [7]). Basically, it 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 [2]. The main concept of Value Stream Mapping has been utilized globally in services, manufacturing, healthcare and construction.

Despite the efforts for sustainability studies in building and infrastructure construction, the sustainability issues in industrial construction remain understudied ([6], [7], [8]). The application of VSM in real construction industry has not received enough attention by researchers due to the difficulty in implementation of VSM in a real construction activity.

This paper aims to propose improvements in construction execution process especially for construction of pipelines using VSM to identify wastes and elaborate a future state. This paper's main contribution is the reduction of wastes and cost in the process flow, establishing an optimum situation in a setting where the integration of VSM and cost methods was used together to develop a systematic framework in Lean Construction for the application in others projects.

The scope of this paper is restricted to the construction of underground pipelines process which attempts to integrate the VSM, LOB and cost calculation based on VSM in construction environment. Consequently, a future map with proposed improvements is developed, as well as the working plans, used to monitor the implementation project [8].

II. Research Scope and Objectives

The main purpose of this project is to recognize the importance of application of value stream mapping in the construction industry by applying the concept on a real construction project. Moreover, it introduces and evaluates the implementation of a cost based VSM in the construction industry. Evaluate the effectiveness for 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 in comparison to the entire lead process time. In this direction, this paper seeks to validate and suggest future state mapping based on the improved results for future standardization by answering the following question: "How can costing of VSM improve the process construction of underground pipelines?"

III. Research Methodology

An explanatory case study of construction of underground pipelines was utilized as the research

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strategy, because it is the most relevant activity in the schedule and budget of the project and, therefore, the proposed improvements would develop a vital impact. The collected data included from different resources: interviews with construction manager and foremen, administrative documents and direct observation. The analysis concentrated on the identification of wastes and problems faced in the process in order to propose improvements.

Construct validity was addressed by comparing the data collected with principles reported in Lean Construction’s literature. Rother and Shook proposed five steps to implement Lean Thinking through VSM; select a family of products, map the current state, analyze the current state, map the future state and elaborate the work and implementation plan (2003). In this study, the stages of productive process for construction were selected instead of selecting a family of products to initiate VSM. Work plan and required manpower was set according to feedback from current state to optimize the process and ensure wastes are minimized in combination with 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 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 comparison between them has been evaluated for estimation and bidding purpose for similar future projects.

IV. Case Study

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 has 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, construction of underground pipelines was selected as a case due to the repetitiveness of the construction activities and easy to understand in the entire construction. As per project contract, the scope of work was 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 pipeline as mentioned in Fig. 1.

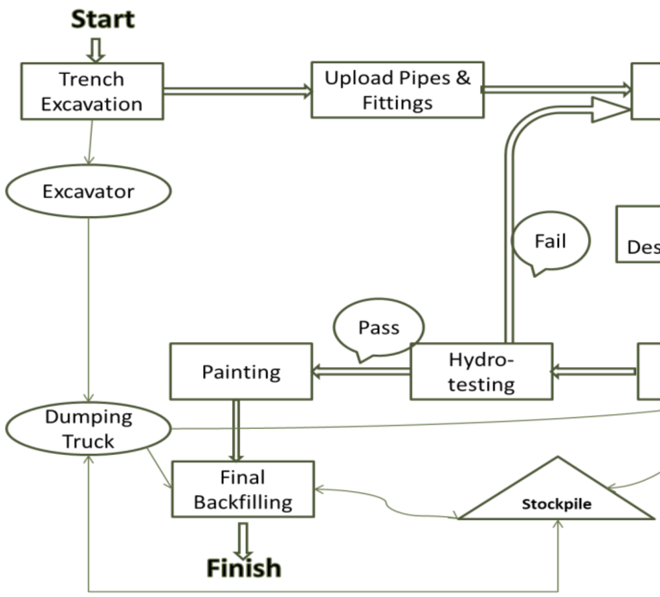

Figure 1. Work flow diagram

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. The construction stages started with excavation of the required trench provides a safe access and safe trench width. The required width is 2.5 meter for pipe diameter of 36 inch. 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. The second stage is 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. The next stage is pipe laying; after the inspection of the trench, the pipes and fittings were shifted by crane and trailer with assistance of two operators, one supervisor and two pipe fitters. The required time for shifting the material to site construction is 60 minutes. After that 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 (leveling) prior to commence with first layer of welding. Welding crew consists of two welders and one helper using two fuel operated welding machines mounted on wheels. The welding crew started with route; pass and last with cap welding. Every welder who made a joint has a unique identifying number. The numbers are marked on 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. 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. Prior to commence with hydro-test of the pipeline, the partial backfilling of the pipeline network shall be completed with assist of three helpers, one supervisor and two operators. The joints shall be exposed to observe the existing of the leak. Next is hydro-testing according to project specification, the test duration is 24 hours and two hours for test preparation. One supervisor and three pipe fitters are required to perform the test. After the test, three painters applied paint for exposed joints prior to proceed with final backfilling. The total required duration to apply paint and curing is 24 hours. The last stage is final backfilling of pipeline network which was carried out in layers and each layer has to be well compacted to ensure the soil and material is uniformly distribution.

A. Waste Times Identification

Waste time 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 between current state and future state. The difference between two times is the waste. The waste for each activity is divided into two types as shown in Fig. 2:

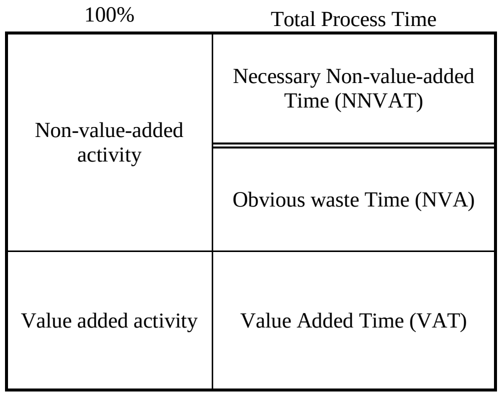

Figure 2. Wastes classification in construction

Hidden waste: Work that does not add value to the product but which may be required under 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.

To explicit in detail, the below Table II illustrates the type of wastes were generated during construction:

TABLE I. TYPE OF TIME WASTES IN CONSTRUCTION INDUSTRY

Waste	**Example**
Overproduction	Pipe fabrication 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 installation or rework.
Inventory	Unused products wait for further processing. Poor planning will increase cost of the worksite and occupy valuable warehouse space.
Motion	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.

B. Current State of Value Stream Mapping

After carefully collecting the production information, the map of the current process was developed. Fig. 3 shows the current state of Value Stream Mapping. The Value Stream for a typical construction of underground pipelines was mapped in detail, which includes flows of information and material. The main purpose for 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.

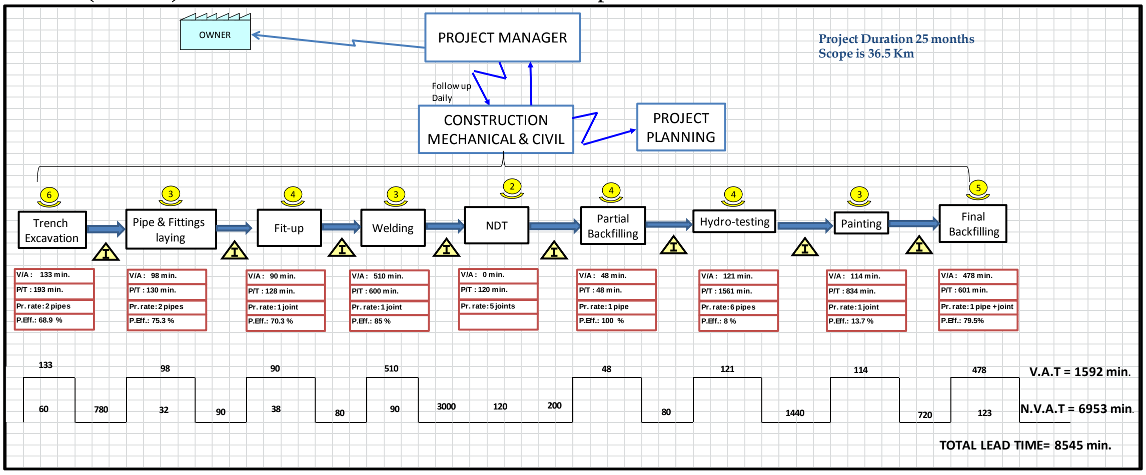

Figure 3 - Current state of VSM for construction of underground pipeline*

As shown in the above Fig. 3, it is noted that the total duration time of the selected case is **8,545** minutes, but the value-added time is **1,592** minutes **(18.6%)** and non-value-added time is **6,953** minutes **(81.4%).**

C. *Takt Time*

In construction, the concept of takt time is different than the manufacturing environment, takt time for the construction will indicate the time in which one pipe joint should be completed according to contract base line schedule. In this research, the project scope is to complete around **3,400 joints** of underground pipeline. The project duration is 25 months. Consequently, the takt time can be calculated accordingly.

$$\textbf{Takt time} = \frac{\textit{Available working time per day}}{\textit{productivity rate per day}}$$

$$= \frac{\textbf{600 minutes}}{\textbf{5}} = \textbf{120 minutes}.$$

The cycle time for all entire construction activities is higher than the takt time. Waiting, waste times and idle manpower are expecting and must be eliminated or reduced. Thus, the construction activities have to be synchronized to achieve the rhythm of takt time and complete within contract duration.

D. *Cost Based Current State of VSM:*

The value stream cost is basically calculated weekly and takes into account of all costs in the VSM. The VSM cost involves the following: (1) Employees cost: is the basic salary including the employee benefit, (2) production supports cost: expenses not directly associated with construction activities such as design, engineering, and procurement , (3) construction equipment cost, (4) construction material cost, (5) facilities and maintenance cost: cost is required to keep equipment or machine in good working condition and (6) any relevant cost.

All costs related to VSM are considered as a direct cost. Any cost outside the Value Stream Mapping is not included in the costing of Value Stream Mapping. Weekly cost of VSM is listed in detail in Table 2. The total cost is $ 19,477 (Table 2) which will be compared with a cost of future state Value Stream Mapping later to investigate and evaluate the difference between these two costs.

TABLE II. COST OF CURRENT STATE ACTIVITIES OF VSM

Current State of VSM	Total Cost ($)
Trench Excavation	3,202
Pipe & fittings laying	1,861
Fit-up	1,005
Welding	1,841
NDT	370
Partial Backfilling	2,034
Hydro-testing	1,279
Painting	962
Final Backfilling	2,423
Monthly Employees	4,500
Total	*19,477*

E. *Suggested Improvement and Future State of Value Stream Mapping*

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.

1. Pull system and synchronize first-in/first-out flow

To expedite the process, every day, an excavation team was assigned to start with excavation activity in advance which would provide enough time for the next activity to start earlier. Moreover, it was 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 (Non-destructive test). Then, the pipeline will be backfilled finally to be ready for final testing.

2. Restructure the sequence of the construction activities (fit-up and welding activities)

Welding activity has high cycle time, therefore and in coordination with the engineering team, a Weld Map Drawing was initiated. Technically, welding map is an isometric drawing that shows the location for all pipe joints in the project. Fig. 4 shows the sample of welded spools in the fabrication shop.

Figure 4. Sample of welded spools

The field engineering department in coordination with construction field would study and investigate thoroughly in detail each joint and specify the joint status with respect to field weld or manufacturer joint weld named as spools.

3. Pacemaker/supermarket and leveling between the construction activities

The concept of Supermarket Pull System between welding process and NDT process was introduced. Basically, the supermarket pull system is a controlled inventory of joints that is 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 schedule to be during the night to perform more tests without any interruption. According to project baseline schedule, the takt time was schedule to produce 5 joints per day to meet the project completion date.

This was suggested to apply the concept of Supermarket Pull system and to ensure a continuous flow. This can be achieved by batch of Kanban (It is a Japanese term 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 as shown in Fig. 5.

4. Manpower leveling and LOB (Line of Balance):

In this research and according to LOB technique, the resource leveling was developed to synchronize the manpower and fulfill the project on time in concurrence with VSM tool. LOB is vertical axis plots cumulative progress of number of joints completed in the project and horizontal axis plots time and sloping lines represent rate of production i.e. number of joints per day

F. Cost Based Future State of VSM

The suggestion improvements were applied to formulate the future state of Value Stream Mapping, and the cost of future state was calculated and summarized in Table III for a week period as previously implemented in the current state.

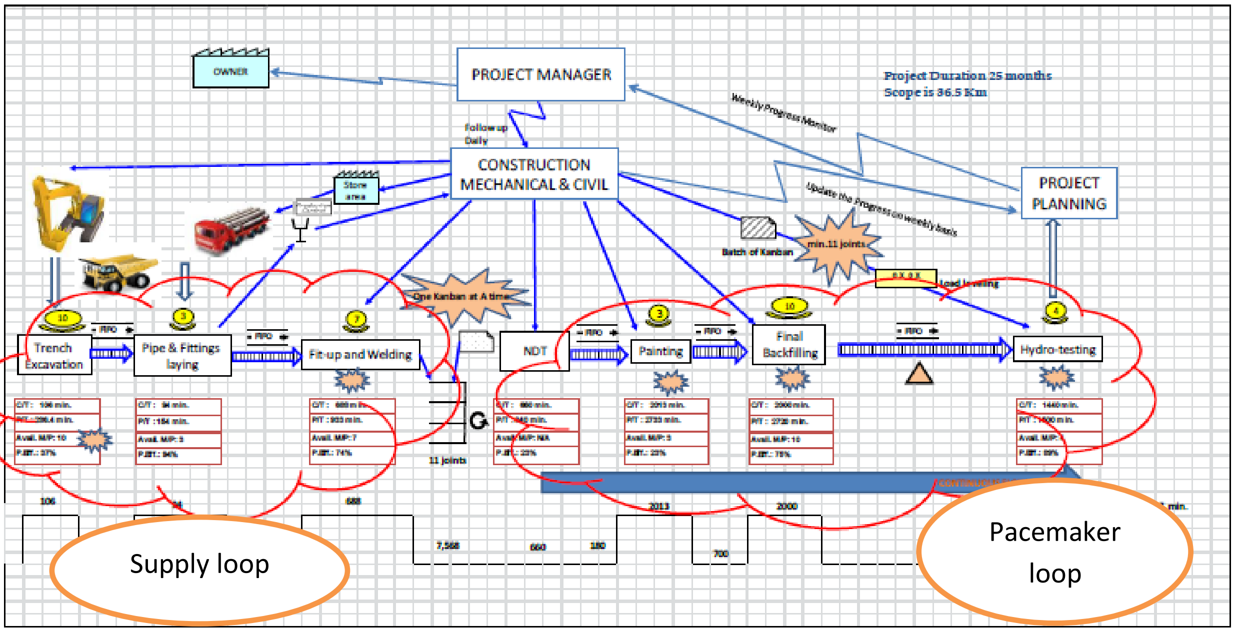

Figure 5. Supply and Pacemaker loops for Future State VSM

TABLE III. COST OF FUTURE STATE ACTIVITIES

Future State of VSM	Total Cost ($)
Trench Excavation	2,535.2
Pipe & fittings laying	1,403.1
Welding and Fit-up	2128.1
NDT	370
Partial Backfilling	
Hydro-testing	1,279
Painting	962
Final Backfilling	2,240.2
Monthly Employees	4,500
Total	*15,417.6*

V. Discussion of Results

The following objectives were outlined after implementation of VSM in construction environment:

- Work process standardization with assistance of continuous educating the site workers to eliminate the time wastes.
- Reduce the problem of waiting time between the processes.
- Expedite the construction activities by developing the concept of supermarket- based supply and pacemaker loops.
- Through the proposed improvement, the total lead time was reduced by **30.7 %** (**8,545** to **5,922** minutes), required manpower was reduced by **12.5 %** and the cost is reduced by **20.8 %** in comparison between two VSM states.

VI. Conclusions and Recommendations

The paper deals with the possibility of implementing the design method of Value Stream Mapping (VSM) supported by that of Line of Balance (LOB) on a construction project focused on the installation of underground pipelines from the perspective of costs. More specifically, the cost implementation of the proposed method enables to reduce the traditional cost associated to this kind of project, compare its current and future costs, and improve its productivity. Although several papers addressed 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 to evaluate the improvements and calculate the cost reduction. This paper tried to cover this gap.

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