Using Value-Stream Mapping to Enhance the Production Performance in Infrastructure Construction Projects in Qatar: A Case Study

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Abstract

Current research on sustainable construction has primarily concentrated on the design and operation phases of projects. However, the enhancement of execution and production phases of infrastructure construction projects have received little attention. In this paper, Value Stream Mapping (VSM) is used, as a Lean production tool, to evaluate production operational waste during the project construction phase. VSM considers the development of process maps that support project managers in diagnosing the current state of production in order to propose future improvements. VSM addresses the underlying causes of issues, as opposed to the symptoms addressed by traditional tools. This paper presents a case study of the application of VSM in the construction of infrastructure projects to improve the manhole and high-density polyethylene pipe connection process. This study's primary contribution is to provide a comprehensive account of the application of VSM in the infrastructure construction industry, confirming its ability to identify the sources of production waste, quantify them, suggest reduction strategies, and develop a TAKT planning. The case study's result demonstrates an effective approach to enhance the performance of construction projects targeting to optimize the resources used and reduce costs, improve quality standards, mitigate the associated wastes and enhance the TAKT time concept in construction of deep utilities in infrastructure construction project.

Keywords: Lean Construction; Value Stream Mapping; Sustainable Construction Management; Enhanced Infrastructure Projects – Qatar; Project Planning and Design

1 Introduction

In order to streamline operations, Rother & Shook (1999) developed a Lean methodology known as Value Stream Mapping (VSM). Information and material flow in a value stream are typically analysed to determine which activities add value and which do not. It has been shown to be effective in decreasing lead time and inventory (Gunduz & Naser, 2019) and it is a core of visual management process (Gunduz & Naser, 2017).

Sustainable practices and efficiency goals are gaining traction in the construction industry. Part of contractual enhancements in infrastructure projects in the State of Qatar, Lean Construction was introduced to support project delivery and minimise programme disruption. Many businesses have employed Value Stream Mapping as a Lean technique to remain competitive in a rising global market.

Value Stream Mapping is intended to remove any production process operations that do not contribute value. Essentially, it is a novel term derived from Toyota's material and information flow diagrams that was created to assist Toyota's suppliers in learning the Toyota Production System. Value Stream Mapping's core idea has been used internationally in services, manufacturing, healthcare, and construction (Gunduz & Naser, 2017). Despite attempts to study sustainable practices in construction and infrastructure development, the construction ecosystem disruption challenges remain a barrier. VSM practice in infrastructure projects is limited that cannot reflect the extent of its impact on identifying and resolving typical operational losses, specifically manhours. Moreover, abstract concepts like "waste," "value," "process," "conversion," and "flow" of processes common to Lean manufacturing can be difficult for construction engineering and management practitioners to grasp and adopt. Therefore, it is crucial for construction professional skills to incorporate practical experience into the curriculum (Ramalingam, 2018). Without a thorough and accurate introduction to VSM, practitioners risk misapplying the method in practice. Therefore, the purpose of this study is to establish a VSM layout that will illustrate to construction practitioners' circumstances where waste is ingrained and must be eliminated. It provides a solid foundation and efficient methodology for construction professionals to develop an effective plan to boost productivity and maximise resource utilisation.

2 VSM in Construction Industry

The value stream mapping process may be divided into six main steps as follows: 1) Identify the process that requires improvement; 2) Establish a map of the process's current state; 3) Select a suitable metric for improvement; 4) Establish a map of the process's future state; 5) Define improvement methods to transfer from the current state to the future state in a manner that achieves the appropriate metric; and 6) Proceed making improvements (Espinoza et al., 2021). Ioannou and Yang (2016) demonstrated that on-site practitioners may use VSM to observe the daily flow of work in order to evaluate the impact of workflow adjustments. VSM may aid in the detection of possible bottlenecks in the building process, hence contributing to the reduction of waste in the construction industry (Kanai & Fontanini, 2020).

3 Identifying Takt Time in Construction Industry

The time that is allotted for the provision of a certain process is called the TAKT time, and it is determined by the demand placed by customers. According to Liker's (2004) research, "it is the heart pulse of one-piece flow." The advantages that are brought to the project by the use of TAKT time include a reduction in variability, a reduction in the total length of the project, and a reduction in the cost of the project (Gunduz & Naser, 2017). In manufacturing, when the consumer demand can be readily determined via the market, the TAKT time may be defined with relative ease. When it comes to determining the demand rate in the construction industry, there are several open questions that arise. One approach is to determine how much time is available to do the task and verify it so that it can be used as the basis for demand; another is to investigate whether or not it is possible to increase the capacity of the trade that moves the most slowly (Frandson et al., 2013). The part of the process that moves the least quickly functions as a bottleneck for the rest of it, which slows it down. It is now the responsibility of the system as a whole to strive towards increasing the pace of output in order to make it match the TAKT time in terms of its speed (Gunduz & Naser, 2019). Here in this paper, the authors utilize Frandson et al. (2013) approach to calculate the TAKT time.

4 Research Methodology

To demonstrate how theory can be applied in the real world, a case study was chosen as the research method because it is appropriate for answering “why” and “how” questions, as well as when the researcher has little or no control over the events, or when the general circumstances of the phenomenon to be studied are contemporary, in a context of real situation (Gunduz & Naser, 2019). The selected case study was suitable since it concentrated on a project that was substantially behind schedule. Therefore, it gave a chance for VSM flow line visualization-based planning to recommend options after presenting their prospective benefits. In an effort to make things as simple and controllable as possible, the scope of this inquiry was restricted to a subset of the project’s underlying structure. The construct validity was addressed by triangulating data from numerous sources, including direct observation, interviews, and documents. External validity is connected to analytical generalisations, in which the researcher attempts to generalise a specific set of data to a broader theory.

4.1 Data Collection

The construction of deep utilities (underground pipeline) is one of the infrastructure construction industry sectors that produce a huge amount of operational waste. As the deep utilities usually form part of project’ critical path, any intermediate delays could lead to a direct impact on the project completion date. For this study, construction process of the manhole and high-density polyethylene pipe connection in infrastructure project was selected as a case due to the repetitive nature of this activity and easiness to visualize it. While the required resources to achieve the planned activities were provided, and no prerequisite (DRAMPPSS: Design, Resources, Access, Materials, Permits, Plants, Safety, Share-understanding) were missing; the Percentage Plan Completed (PPC) for construction of Road “A” was 54%. An initial analysis shows a slow progress during the backfilling of utilities trench. GEMBA walk was conducted by construction team to look at work-in-process, understand the current state and identify the obstacles. Outcomes of the walk highlight that the manhole connection process is the bottleneck activity of the backfilling of construction of road “A”.

VSM is a powerful tool used to provide a macro level view of sequence of activities that are rarely fully understood. This view supports tactical improvements to remove obstacles to the flow and increase customer value. After data collection, the current state of VSM was developed (mapping of process, material, and information flows), the current metrics were recorded (i.e. value-added (VA), non-value added (NVA), Lead time (LT), manpower, batch size, and Takt time) as shown in Figure 1.

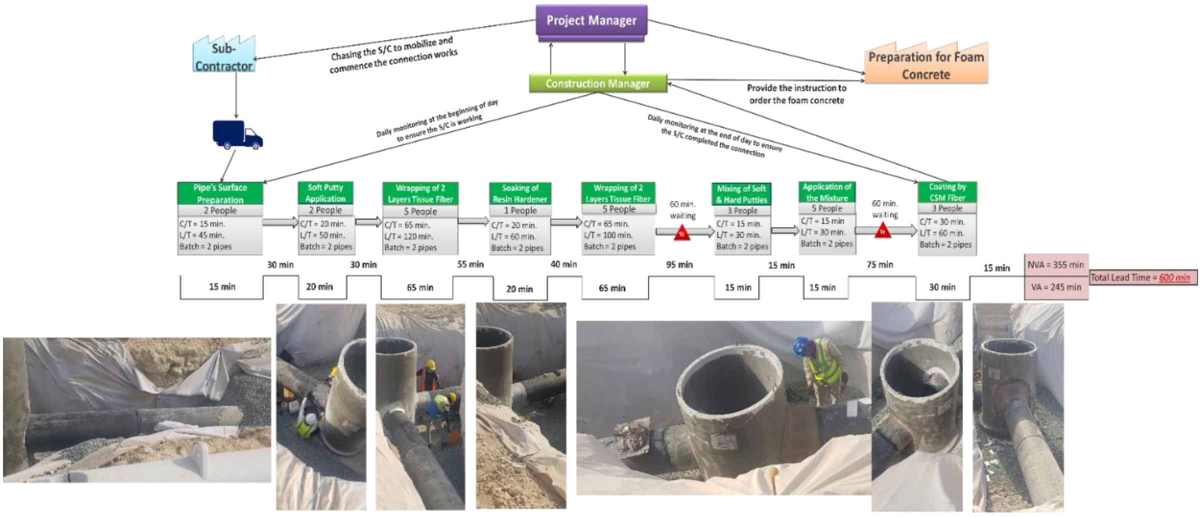

Fig. 1: Current State of Manhole’s Connection Process

4.2 Future State of VSM

Moving from current state to future state, the following countermeasures were proposed to enhance the process of the manhole connection. Table 1 provides a tracking template for the VS transformation plan:

- Implementing standard work for referral process using an approved method statement.
- Assigning a competent Forman.
- Increasing the batch size of 4 pipes per day by utilizing and monitoring a manpower properly to increase VA and reduce NVA.
- Introducing a supermarket after completing the installation of 4 pipes to perform Barcol hardness test to control and improve the quality of HDPE pipe connection with manhole.

Table 1: Value Stream Transformation Plan

Value Stream Transformation Plan			
Value Stream	Manhole's Connection with HDPE pipe	**Scheduled Review Dates**	
Executive Sponsor	Project Team	Weekly	21-Feb-2022
Value Stream Champion	A.N.	Weekly	28-Feb-2022
Value Stream Mapping Facilitator	A.N.	Weekly	7-Mar-2022
Date Created	4/2/2022	Weekly	14-Mar-2022

Kaizen Burst No.	**Measurable Target**	**Proposed Countermeasure**	**Exec. Method***	**Owner**	**Planned Timeline for Execution**												**Status**
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
1	Batch Size shall be targeted of 4 pipes per day	Implementing standard work for referral process using an approved method statement	KE	Project Manager													**100%**
2	Monitoring the work activity and installation closely	Provide VSM Training	JDI	Project Manager													**100%**
3	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager													**75%**
4	Targeting of batch size of 4 pipes per day. The activity "mixing" is re-arranged in parallel with another activity.	Utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager													**75%**
5	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager													**75%**
6	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager													**75%**
7	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager													**75%**
8	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager													**75%**

9	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager		**75%**
10	Supermarket is introduced after completing the installation of 4 pipes to perform Barcol hardness test	Improving the quality of Manhole's connection with HDPE pipes	KE	Project Manager		**100%**
11	Targeting of batch size of 4 pipes per day	Reducing manpower, utilizing manpower properly, increase VA, and reduce NVA	KE	Project Manager		**75%**

Agreement		
Executive Sponsor	**Value Stream Champion**	**Value Stream Mapping Facilitator**
Signature:	Signature:	Signature:
Date:	Date:	Date:

* Execution Method = JDI (Just-do-it), KE (Kaizen Event), or Proj (Project).

After identifying and eliminating operational wastes, the future state was developed with a clear picture of how the process should look. Implementing was utilized as a blueprint to standardize and sustain the process of developing a future state of VSM to maintain a continuous flow as indicated in Figure 2.

To prevent delays, TAKT time was introduced to the procedure. With little buffers, the activities were made as repetitious as feasible. Without interruption, the same crew will go from zone to zone doing identical activities. This will save resources and increase efficiency. The process included two steps, with the first stage's resources and therefore production rate remaining unchanged. Activities have been synchronised in accordance with pace to ensure that all activities are effective from the moment they begin until the time they conclude. The second stage was modified in accordance with TAKT time. The summary metrics and advantages of VSM are shown in Table 2.

Table 2: Value Stream Transformation

Value Stream Mapping Summary Metrics				
Executive Sponsor	Project Team	**Event Name**	Manhole Connection with pipes	
Value Stream Champion	A.N.	**Event Start Date**	04/02/22	
Facilitator	XXX	**Coordinator**	XXX	
Activity	**Processing Time (Hours)**	**Lead Time (Hours)**	**%C&A**	**Takt Time**
Current State				
Pipe's Surface Preparation	15	45	85.0%	300 min
Soft Putty Application	20	50	75.0%	
Wrapping of 2 Layers Fiber Tissues	65	120	95.0%	
Soaking of Resin Hardener	20	60	75.0%	
Wrapping of 2 Layers Fiber Tissues	65	100	75.0%	
Mixing of Soft & Hard Putties	15	30	75.0%	
Application of the Mixture	15	30	75.0%	
Coating by CSM Fiber	30	60	75.0%	
Future State				
Pipe's Surface Preparation	30	35	90.0%	109 min
Soft Putty Application	30	40	85.0%	
Wrapping of 2 Layers Fiber Tissues	80	90	95.0%	
Soaking of Resin Hardener	30	50	95.0%	
Wrapping of 2 Layers Fiber Tissues	80	90	95.0%	

Mixing of Soft & Hard Putties	30	30	95.0%	
Application of the Mixture	20	30	95.0%	
Coating by CSM Fiber	45	50	95.0%	
VSM Metrics	**C. S.**	**F. S.**		
VA	245	345		
LT	600	435		
NVA	355	90		
% VA	40.83%	79.31%		
Manpower	8	5		
Batch Size	2 pipes	4 pipes		

Takt planning can be developed based and after the implementation of VSM to maintain a continuous flow by using TAKT time. Dividing workstations by zones, each zone includes all locations that have same production rate for a certain task generated from VSM.

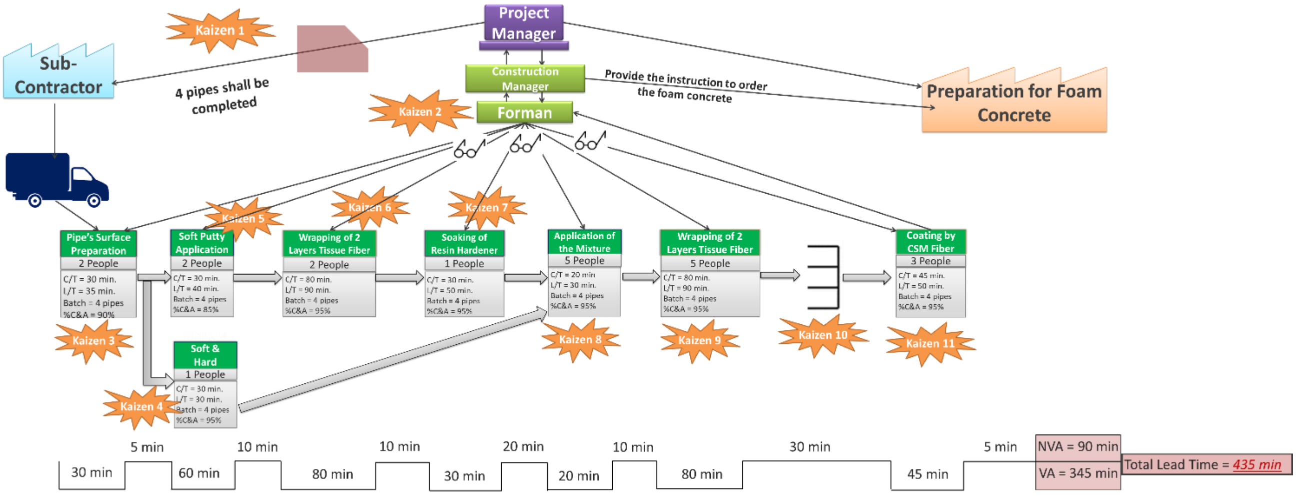

Fig. 2: Future State of Manhole's Connection Process

5 Discussion of Results

The objectives of this research have been accomplished mainly through demonstrating of:

- VSM is a Vital Visual Management and Lean tool to visualize materials and information flow in the process of the manhole and high-density polyethylene pipe connection process in infrastructure project.
- The potential of VSM to enhance the performance of construction projects targeting by reducing the construction Lead time by 27.5%, increase the VA by 30%, reduce the manpower by 37.5 %, reduce the NVA by 74%, and increase the batch size by 50%.
- Optimize the resources use through TAKT time to level the resources for each work trade and TAKT zone.
- Enhance the quality of each process's output and handoff between two trades, meaning that they do their work without having to correct it.
- Mitigate the associated wastes in construction of deep utilities in infrastructure construction project.
- Develop a TAKT planning through splitting the zones to ensure a proper resources utilization. In this paper, the construction area is splitted into 6 optimized TAKT's zone to ensure a proper resource optimization.

6 Conclusion

The optimization of both time and resources within the construction industry is becoming an increasingly important factor for the industry's success, and as a consequence, new planning and scheduling methodologies are being suggested for implementation. The purpose of this study was to provide a methodical approach to using VSM and TAKT time planning that is based on the idea of location-based management. A local initiative of modest to high scale served as the basis for the case study example. Because so many of the construction jobs included in this case study were similar to one another, it was the ideal choice for this article. Alternatively, the applicability of this technique could be restricted for more complicated building projects that include a large number of non-repetitive jobs. When tasks were first represented using the prevalent mode of operation, it was discovered that there were significant time wastages in the form of extra time buffers.

In addition to this, it was discovered that the number of resource allocation was not balanced. Following that, two measures were taken in order to attain production according to TAKT time: (1) the introduction of phased production rather than "as soon as feasible" while maintaining resources constantly. (2) The process of aligning the production rates of the various tasks and arranging them to be equivalent to the TAKT time that is being applied.

According to the findings, the total length of the connection process after the aforementioned adjustments has decreased in accordance with the existing conventional working style. This results in a reduction of the project duration. In addition to this, the future state implemented VSM and TAKT time-based schedule resulted in the optimization of a resource. The findings of the case study indicate that working to the TAKT time assists in the establishment of a continuous flow, which results in less waste, a shorter duration, and thus, lower costs.

This paper has offered a methodical approach to the determination and application of VSM and TAKT time to the various stages of the infrastructure project planning process. It has also been determined that using TAKT time as a pacing mechanism for productivity results in less waste. In the future, research might be done to expand on this subject by evaluating the approach and digitization of application and using VSM in large-scale projects.

Authors find that VSM can be combined with other process mapping tools such as SIPOC to harness the flow of activities and information within construction activities. This will provide further cases to be studied.

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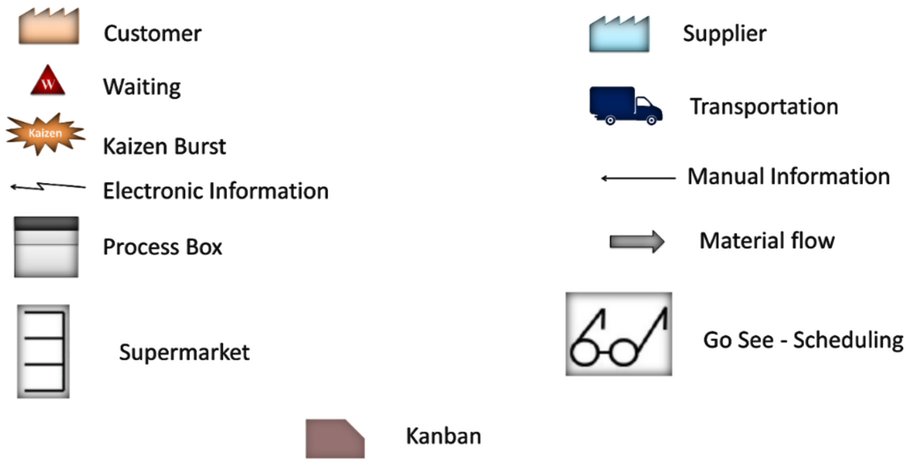
Appendix A: Symbols Used in VSM



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