Simulation-based Value Stream Map for Manual Steel Fabrication Workstations

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ABSTRACT
Industrial steel fabrication encounters numerous difficulties in having efficient steel production. These difficulties are usually caused by the presence of bottlenecks that are not easily identified using traditional methods. Value Stream Map (VSM) is a lean tool that can be used to identify process inefficiencies and plan to minimize non-value-added activities. However, traditional VSM is not designed to be applied in a non-repetitive work environment especially when workers are highly involved in the process such as in manual steel fabrication processes. Therefore, the typical VSM requires modification to achieve the desired outcomes. Hence, the goal of the current study is to produce a current state VSM and integrate it with a simulation model to plan for an optimized future state. The scope of this study is limited to the fitting and welding workstations since they represent the typical manual processes in the steel fabrication industry. The outcomes of this study will provide the ability to identify improvement opportunities. Also, it will allow for a precise quantification of the improvement gain and time savings. Decision-makers in the steel industry will have accurate information about the processes in fabrication plants. Also, they will be able to make evidence-based decisions that will ensure reduced waste and cost for steel operations.

KEYWORDS
Steel Fabrication, Value Stream Mapping, VSM, Simulation, Discrete Event Simulation

INTRODUCTION
Work improvement in the steel manufacturing industry is continuing to evolve with the use of various methodologies. One of these methodologies is the use of Lean Manufacturing. Nowadays, many companies have adopted the concept of Lean Manufacturing, which allows them to determine the true value of their processes and eliminate the non-value-added activities (Hines and Taylor, 2000). Lean Manufacturing can be defined as a methodology that aims to reduce the use of resources in a manufacturing process. It entails identifying and removing waste, which is described as any operation that does not add value to the customer (Saied et al., 2019).

The steel fabrication industry encounters some challenges in its progression toward having efficient steel production (Hofacker and Gandhi, 2009). Since many industrial steel fabrications implement an off-site manufacturing approach, it is important to ensure that bottlenecks are identified and prevented to reduce the impact on work efficiency and productivity. Dealing with bottlenecks can be more complicated depending on the nature of the work. For companies that experience huge bottlenecks, adopting modern lean thinking methods can help operate their plants at full capacity, even during busy periods.

Tracking and improving productivity in steel fabrication plants is a challenging issue, but it can even be more challenging when the fabrication work is performed manually. Fitting and welding stations are typical manual workstations in a steel fabrication plant. Since these stations are usually downstream stations, they tend to experience bottlenecks when the production in the upstream stations is higher than what they are able to process. They also tend to have a non-repetitive work environment where every assembly that arrives at the station can be subjected to a different work process than the assembly before.

This study was conducted at the industry partner's steel fabrication shop (fitting and welding stations). The fitting station is a downstream station with typically four benches and a fitter at each bench. The fitting station receives beams through a conveyor belt from a computerized Numerical Control (CNC) machine, then the beams are sent to one of the four benches, generally based on work complexity and workload on each bench. The process of fitting parts to a beam or a column is completed manually by either tacking or bolting the parts. The welding station is a downstream station with typically two benches and a welder at each bench. The welding station receives beams/columns from the fitting station after tacking all the parts that need to be welded. The process of welding parts to a beam or a column is completed manually by welders.

One of the most common lean tools is VSM. VSM is an improvement technique that identifies bottlenecks and their sources in order to continuously achieve a leaner production operation (Rother and Shook, 1999). Some lean manufacturing tools have been applied based on VSM in the steel industry (Rocha, 2014). VSM is a versatile tool that highlights the source of waste and helps identify areas that need improvements. VSM focuses primarily on identifying waste, reducing production time and making the production process more efficient (Saied et al., 2019). However, companies that rely on traditional approaches in their manufacturing systems are usually reluctant to implement Lean Manufacturing tools such as VSM due to the lack of evidence of quantifiable gains that can be achieved. Therefore, simulation can be seen as an obvious tool that can be used with VSM to quantify the gains (Abdulmalek and Rajgopal, 2007).

This paper is structured as follows: (1) a literature review on VSM and its integration with simulation, (2) a description of the proposed methodology to develop current state VSM, simulation model, and future state VSM using collected data at the steel plant, (3) the study results and discussion, and (4) conclusions and recommendations.

LITERATURE REVIEW

This section provides a literature review on the use of VSM in steel manufacturing environments. The implementation of VSM is becoming popular around the world. VSM has been implemented in various countries such as Malaysia (Zuraidah et al., 2014) , India (Gurumurthy and Kodali, 2011), Kuwait (Abdulmalek and Rajgopal, 2007), South Africa (Munyai et al., 2019), United Kingdom (Shararah et al., 2011), United States (Abdullah, 2003), and Egypt (Saied et al., 2019).
The main goal of VSM is to identify all types of waste in the value stream and to take steps to eliminate or minimize them as much as possible (Rother and Shook, 1999). Lean tools such as

VSM are considered to be powerful tools for the identification and elimination of all types of activities that do not add value to customers (Davim, 2018). Duggan (2018) indicated that VSM has proven to simplify the complexity and allow numerous lean improvement implementations in a complex manufacturing environment where several processes have a complicated product flow.

Even though VSM can transform the manufacturing process into a lean operation, it is still a static tool that has a limited ability to dynamically capture the behaviour and complexity of a system (Lian and Landeghem, 2002). One way of mitigating this complexity is by integrating VSM with a simulation model, e.g., Discrete Event Simulation (DES). There have been some attempts to integrate DES with the traditional VSM to allow for a better project envisioning (Wang et al., 2009). Multiple literatures such as McDonald et. al, (2010), Braglia et. al., (2011), Lian and Landerhem, (2007), and Parthana and Buddhakulsomsiri, (2012), indicated that simulation based VSM is able to provide information about the dynamic nature of the production process and able to shorten the time to evaluate the effect of any changes made to the system. Also, Munyai et al. (2019) indicated that bottlenecks that limited the performance of the system were easily identified after implementing VSM using DES.

Abdulmalek and Rajgopal (2007) described the application of VSM with simulation in a continuous process industry such as the steel mill industry. Similarly, Zuraidah et al. (2014) implemented lean waste analysis using VSM and DES model in a metal manufacturing industry in Malaysia. The performed lean waste analysis provided them with the ability to identify sources of waste and explore various alternatives to improve the process on the existing production system. Also, it allowed for a reduction in Production Lead Time (PLD), value-added time, and the number of operators required to complete several tasks.

While comparing the methodology used by Abdulmalek and Rajgopa (2007) and Zuraidah et al. (2014), they both used a systematic way of generating future state VSM. The future state VSM was developed after answering multiple questions. The research and methodology completed in this paper follow a similar basis to that proposed by Zuraidah et al. (2014). However, there are some limitations when it comes to applying the traditional VSM approach in various steel fabrication plants due to the variations in the design and shape of the steel assemblies.

Based on the reviewed literature, very limited studies examined the integration of simulation and VSM in manual steel fabrications processes (e.g., fitting and welding processes). Also, none of these studies was implemented in Canada. Therefore, the proposed work is intended to reduce the gap by integrating VSM and simulation in manual steel fabrication workstations such as fitting and welding workstations in Canada.

METHODOLOGY

The proposed methodology in this paper intends to apply lean tools through the integration of VSM and simulation. The work started by observing the work activities in fitting and welding stations for two days. Then, a data collection sheet was developed. The data collection sheet contained four tables: study information, assembly information, assembly characteristics, and a table for the five different work phases. The five work phases are loading assembly, preparing assembly, fitting/welding activities, inspection, and unloading. The time spent to complete these phases was used to estimate the processing time of assemblies.

To estimate the processing time, collected data were transferred into an Excel sheet to conduct statistical analysis. The analysis included conducting correlation and regression analysis to provide productivity measures and predictive models (regression equations). Regression equations that estimates the processing time were generated using the dependant and independent variables that had the best correlation.

Using the results from the correlation and regression analysis, current state VSM was created and integrated with a simulation model to produce the future state VSM. The general approach to creating VSM was based on the well-known VSM book by Rother and Shook in 1999. The scope of the VSM and simulation was limited to fitting and welding stations as they are not efficient compared to other steel fabrication stations that are mainly automated or semi-automated.

The simulation frequency of products intervals in these two stations is determined based on experts' judgment. The authors conducted a one-month time study through the manual stations to model the product and process within the simulation environment. The simulation model illustrates current bottlenecks and inefficiencies in steel fabrication by quantifying the amount of work in progress before each station. Next, the authors present modifications to the current condition to improve efficiency in these steel fabrication stations.

The simulation product modelling investigates the key variables that are related to the work needed at each station. In the fitting station, the key variables, based on correlation and regression analysis as well as the expert's knowledge, are (1) parts tacked, (2) parts bolted, and (3) number of copes. These key variables determine the complexity and the processing time of every assembly.

The simulation process modelling allocates resources and determines the processing time based on key variables of each product. The resource allocation process is conducted based on the current strategy in the fitting and welding stations. The estimation of processing time for each station is performed by a Linear Regression (LR) predictive model. This predictive model is implemented in sci-kit-learn in Python because of its robust and convenient tools.

The proposed simulation model is implemented using the Simphony.Net for Discrete Event Simulation (DES). Simphony.Net provides two environments for simulation: (1) graphical user interface (2) programming language in Visual Basic.Net. Using a programming language for simulation enables users to (1) link the simulation to the database and conveniently manipulate the data, and (2) improve simulation by adding flexibility within a programming language. This study utilized both simulation environments in Simphony.Net to internally verify the simulation model.

The program is linked to a central database that makes the system parameters responsive to changes. The developed system reads input data from the database to model the project. The final outputs of the simulation process are stored in the database. **Figure 1** shows the simulation model scope. This study proposes a simulation environment that models the work in fitting and welding stations and estimates stations' current inventory and productivity based on the processing time at each of these stations.

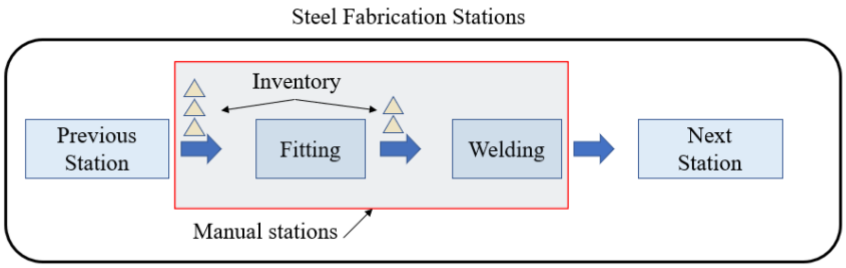

Figure 1: Scope of the simulation model

Figure 2 presents the general outline of the simulation model in four modules: (1) input module simulates the product's interval flow and key variables to the manual stations. This module provides the product flow to the fitting station, and hence it determines the inventory size in the fitting station. The programming environment utilizes key variables from the predictive models to calculate processing time at each station. (2) The fitting module has three main steps in this framework; first, it assigns available resources to each product. Next, this module calculates the processing time for each product at the station, and finally, after processing time, it releases the allocated resource and sends the product to the next station. (3) The welding module follows the same steps as the fitting module. (4) Output module determines the inventory size at each station by observing each station's input and output flow.

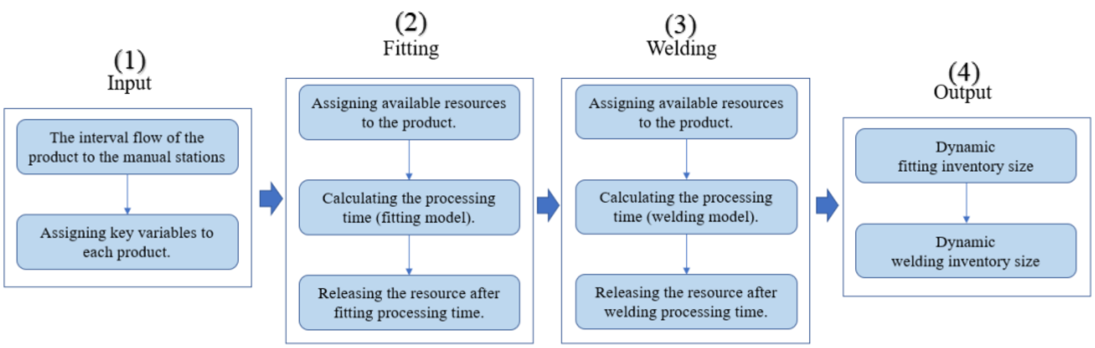

Figure 2: The framework of the simulation model

RESULTS AND DISCUSSION

After implementing the methodology described in the previous section, the current state VSM shown in **Figure 3** shows the important measures that quantify the work and operation at the industry partner's steel fabrication shop. This VSM is a snapshot of the complete VSM for the whole plant. This VSM represents the current condition as well as important measures of each of the fitting and welding stations. The data box associated with each station contains information about the average cycle time (C/T), value-added (VA) time, non-value-added (NVA) time, VA%, work amount measure, and the number of work shifts. The work shift is a regular production time of 8 hours per shift.

This VSM shows that the percentage of value-added activities in the welding station (63%) is higher than the fitting station (46%) since welders spend more time on value-added activities such as grinding and welding. The current average inventory size is 176 assemblies in the fitting station and 107 assemblies in the welding station. However, to ensure a steady flow in the plant, a simulation model was produced to optimize the inventory. The simulation results show that the inventory size should be reduced to 22 assemblies in the fitting station and 34 assemblies in the welding station. In order to achieve this optimization, the C/T should be lower than the current values. Based on simulating the work activities in both stations, the new C/T should be 25 minutes in the fitting station and 21 minutes in the welding station. The following table shows the significant inputs and outputs for the simulation model.

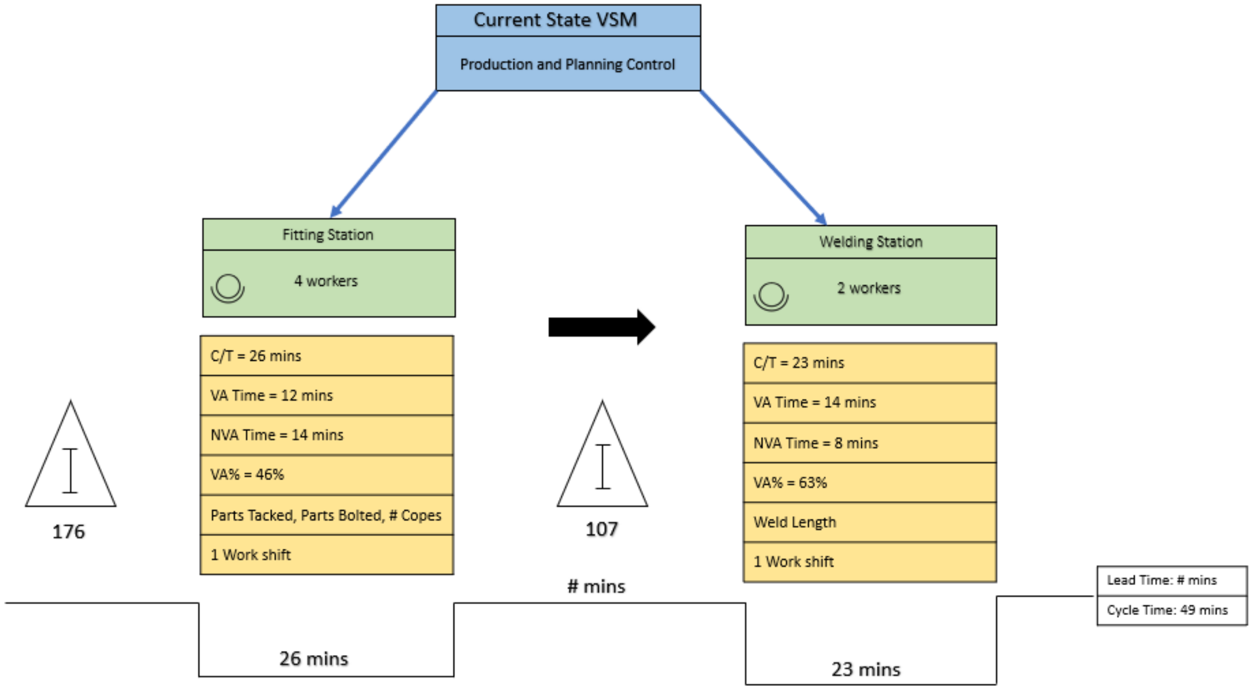

Figure 3: Current state VSM generated manually from the collected data

Table 1: Simulation results summary

	Fitting Station		*Welding Station	
Coefficient	1	0.95	1	0.9
Assembly/min	6.7	6.7	6.7	6.7
Inventory size	176	22	107	34

*65% of assemblies in the fitting station are moved to the welding station

To achieve the desired future state VSM (eliminate process waste present in the steel plant), the following modifications to the current operation at the industry partner plant are recommended:

- Reduce time spent on assembly preparation (reviewing drawing and marking assembly) by implementing augmented reality in the plant. Also, most augmented reality could also provide production and productivity reports that allow for real-time data tracking.
- Reduce waiting time for crane by using a beam flipper handling tool. A beam flipper tool is a material handling tool that can be installed to flip, rotate, and position a beam without the need to use the overhead crane. This could also improve safety and eliminate the demand for labor help in material handling. **Figure 4** shows the future state VSM after implementing the simulation results.

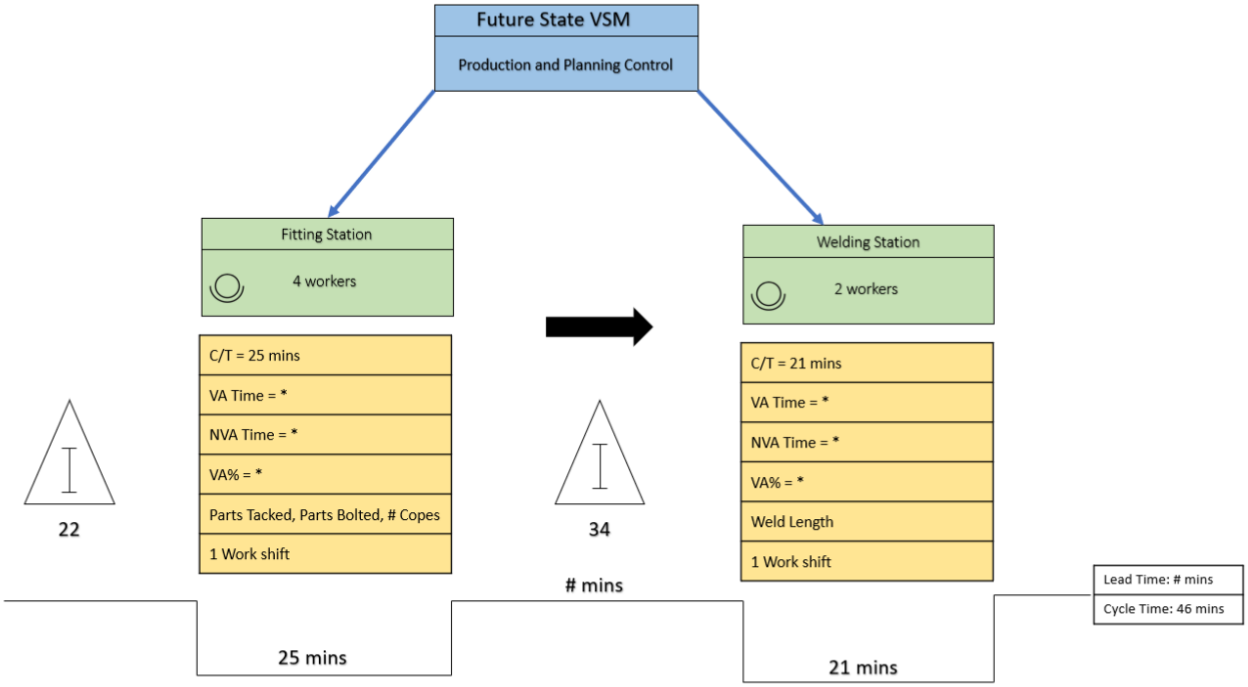

Figure 4: Future state VSM generated via a simulation model

Figure 4 shows a reduction in the overall C/T in the future state VSM. The components that are denoted by a " * " means that the change can be in any one of them to achieve the reduced C/T.

CONCLUSIONS

Integrating VSM and simulation has been widely identified as one of the most effective tools to improve productivity. Using simulation helped capture the complexity of the manual steel fabrication workstations and evaluate the effect of any changes that are made to the existing system. The simulation results of the steel fabrication shop inventory showed that there is a need to reduce the average C/T in the fitting station from 26 minutes to 25 minutes (5% reduction), and in the welding station from 23 minutes to 21 minutes (10% reduction).

Even though the implementation of VSM and simulation in this study provided a great opportunity to identify potential areas of improvement, the study still had some limitations. One limitation is that the VSM was not applied to all the processes in the plant (just for two stations). However, these two stations are considered the typical workstations in the plant. Therefore, the same method can be applied to all the other stations for future work. For future work, when mapping all the processes in the plant, various lean tools such as the 5 Whys technique and Pareto Analysis can also be used to examine the possibility of enhancing the study outcomes.

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