Discrete Event Simulation Enhanced Value Stream Mapping: An Industrialized Construction Case Study

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Abstract

Research Question/Hypothesis: Can a production process design framework created by integrating Value Stream Mapping (VSM) and Discrete Event Simulation (DES) be used to assess the production system performance, as predicted by a future state design of small and medium sized enterprises (SMEs) working in industrialized construction?

Purpose: To explore a production process design framework in which VSM is used to identify doable improvements and DES provides analytical evaluation of them.

Research Method: The demonstration was carried out at a Swedish SME industrialized construction component manufacturer

Findings: VSM is unable to evaluate analytically the performance of the future state design. This inability leads to unnecessary implementation iterations. VSM assumes a deterministic model and cannot describe the dynamic behaviors of a system. The dynamic behavior of the construction processes will result in the future state design not performing as expected. However, analytically evaluating the future state with DES helped the case company to implement a new production process design.

Limitations: DES modeling is still time-consuming and needs skilled professionals, the cost of which can be prohibitive for SMEs as demonstrated in this case study.

Implications: The integration of DES and VSM provides a framework to evaluate and communicate the outcome, hence enhancing the application of VSM.

Value for practitioners: A lean framework, which can be used, for industrialized construction processes especially by SMEs with very limited resources, to validate changes before implementing them.

Keywords: Value stream map, Discrete Event Simulation, Industrialized Construction, Small Business, Process Design

Paper type: Case Study

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Introduction

The loosely-coupled construction supply chains created by the involvement of many interdependent sub-contractors and suppliers destabilize the production process on-site (Bertelsen and Koskela, 2002). Industrialized construction methods (Koskela and Vrijhoef, 2001) that use prefabrication and modularization (Lennartsson and Björnfot, 2012) have been suggested as one approach to reducing process variation by standardization (Alves et al., 2006; Höök and Stehn, 2008). However, a trade-off between Lean and Agile production strategies is needed to adapt to fluctuations in demands and the customization of the construction value chain (Lu, Olofsson and Stehn, 2011). A predictable outcome enables efficient use of the production system. Variation in the supply chain can be detrimental and must be properly considered in the design of new production systems in order to reduce the financial risk of investments in manufacturing resources (Singh, 1986). A majority of Swedish companies involved in industrialized construction supply chains are small and medium-sized enterprises (SMEs) with limited resources and it is essential for them to be able to pre-evaluate changes to their production system design.

The Lean method of value stream mapping (VSM) enables a process owner to focus on production system improvements. The execution of a VSM should be iterative and incremental, i.e., taking several small steps that will lead to an improved production process (Rother and Shook, 2003). The incremental approach is partly due to the problems associated with accurately predicting the effects on process performance of a future state design produced by VSM (Marvel, 2009). In addition, the incremental implementation may result in unnecessary iterations (Ferrin and Muthler, 2002). Simulating and testing new processes before implementation is a way of undertaking low-risk experiments, without endangering an organization (Sterman 2000). This becomes even more important for SMEs that are part of a construction supply chain, with limited resources to use for process change. SMEs often do not have the financial capacity required for testing new processes (Ylinenpää, 1997).

The purpose of this case study is to investigate and validate a process design framework by integrating VSM and Discrete Event Simulation (DES), in order to assess the production system performance as predicted by a future state design. A demonstration of it was carried out at a Swedish SME industrialized construction component manufacturer.

Literature Review Value Stream Mapping and Simulation

The literature review has been conducted by selecting papers describing VSM and DES, from the databases; Taylor & Francis Online Journals, Science Citation Index Expanded (Web of Science), iVerse ScienceDirect (Elsevier), OneFile (GALE), Google Scholar and Lean Construction community. Using the keywords *Discrete*, *Event*, *Simulation*, *Value*, *Stream*, and *Map** yielded a total of 348, from which 23, published in peer-reviewed periodicals discussing Lean and DES were studied. It is important to note that the combination and integration of Lean and DES is of interest to a large community. The published papers appear in a wide range of journals ranging from manufacturing e.g. The International Journal of Advanced Manufacturing Technology, Journal of Manufacturing Technology Management and International Journal of production Economics, to construction applications, e.g., Engineering Construction and Architectural Management,

Building research & Information and Lean Construction Journal. From the 23 papers, 8 papers that described VSM and DES exclusively were selected (Table 1). All of these papers, that combined VSM and DES, described case studies, but none of them built any hypothesis or constructs regarding the combination of methods that integrates VSM and DES for process design evaluation, or defined the interaction between VSM or DES components. The selected literature shows that an approach to systemize a framework is needed.

Table 1: Literature Review results

Reference	Industry	Results
McDonald et al., 2002	Manufacturing	DES can be an integral part of the VSM in order to complement the future design
Abdulmalek and Rajgopal, 2007	Process	Data provided by DES is used to evaluate and validate VSM process design
Lian and Landeghem, 2007	Manufacturing	Integration of DES with VSM enhance information for process design
Agyapong et al., 2009	Manufacturing	Transforming static models (VSM) into dynamic (DES) adds future process design reliability and validity
Anand,G. and Kodali,R., 2009	Manufacturing	DES allows visualization and validation of the VSM future process design
Marvel, 2009	Manufacturing	DES increase effectiveness in evaluating VSM future process design variability
Yu, 2009	Construction	VSM combined with DES increases understanding of the behaviour of future process design
Gurumurthy and Kodali, 2011	Construction	DES allows visualization and validation of the VSM future process design

Value Stream Mapping

VSM is described as an iterative method for mapping and analyzing value streams (Rother and Shook, 2003). Its purpose is to quantify and communicate production process characteristics such as material and information flows as well as non-value adding activities (Lasa et al., 2008). It is used for developments such as lead time reduction, throughput increase and reduction of work in progress (WIP) (Alvarez et al., 2009). VSM consists of the elements "mapping the current state gap", the "future state design" and a "yearly value stream plan". The current state gap presents a visual representation of the value adding and non-value adding activities in a process. The future state design is a value stream where the identified problems of the current state have been remedied. The yearly value stream plan forms the implementation plan, which closes the gap between the current and the future state, as well as determining the schedule of necessary changes

needed to improve the production process as defined by the future state design (Rother and Shook, 2003).

A particular disadvantage of VSM which reduces its usefulness is that is does not provide 'hard facts' for managerial decision-making, merely indicates a direction. The process owner should use other methods to find 'hard facts' to solve the root cause of any problem (Khaswala and Irani, 2001). VSM has also been criticized for being deterministic since it does not take into account fluctuations in demand (Hampson, 1999) or process variability (Hines, 2004). Variability is a key parameter in the design of processes and defining inventory levels.

An important conclusion is that VSM does not have the ability to analytically predict the effects on the future performance of a production system. It's as a result of discussion and a consensus of opinions, rather than a result of an analysis.

Improving the Value Stream

Value stream performance can be described in terms of lead time, inventory and operational costs (Brewer and Speh, 2000). Lead time is the time from when an input enters a production process to its exit, i.e., the time needed to produce output. Inventory is the stock level or input that the project needs to transform into output. A reduction of work in progress (WIP) and inventory levels gives shorter lead times according to Little's law (Hopp and Spearman, 2000), and a more flexible process (Simonsson et al., 2012). Operational costs are costs connected to the transformation of input into outputs; these include wages, rental of machines, other resources and overhead costs.

The need for validation before changing production processes is important for SMEs. These companies are often economically vulnerable and more dependent on a steady flow of transactions. In addition, ownership, management and control are normally handled by one person, implying a simpler decision-making process than in large enterprises. However, in smaller organizations, ideas that reach the introduction stage without having been first evaluated using a rigorous stage gate process can cause uncertainty at the point when managerial decisions require validation of those ideas; this is often connected to monetary commitments that are made prior to implementation (Pitta, 2008).

Even though it has been suggested that increasing the amount of information can improve this situation (Forsman, 2011) and that a reduction in uncertainty increases the need for information (Daft, 1986), it is not obvious whether more information will lead to better decisions. Decision-makers often lack important information and consequently, uncertainty is present throughout the decision-making process (Levander et al., 2011). Therefore, simulation, experimentation and evaluation of the future behavior of a new system may help to support the managerial decision-making process for SMEs.

Discrete Event Simulation

Simulation is the method of developing and experimenting with computer-based models of operations, such as construction processes, to analyze and evaluate the behaviors of a system (AbouRizk, 2010). Discrete Event Simulation (DES) has been used in construction process simulations since the development of the CYCLic Operations Network (CYCLONE) (Halpin and Riggs, 1992). Using DES, process behaviors can be evaluated before implementation and re-designed until the desired performance has been. DES has been

proven to be an effective technique in predicting and evaluating the behaviors of systems (Banks et al., 2000). After the introduction of CYCLONE, there have been many construction simulation programs developed, such as UM CYCLONE (Ioannou, 1989), STROBOSCOPE (Martinez and Ioannou, 1994), ABC (Shi, 1999), Simphony.net (Hajjar and AbouRizk, 2002), RiSim (Chua and Li, 2002) and SDESA (Lu, 2003). Recently DES has been used to improve construction value chain performance (Lu et al., 2010) and is viewed as a Lean method for re-engineering a production system (Al Sudairi, 2007). However, simulation is useful in evaluating the performance of a particular design, but not in determining the optimal design from a large set of potential designs (Simchi, 2003).

The integration of lean, VSM and DES provides convincing arguments for the adoption of lean. A simulation model combined with VSM was developed to examine different scenarios in order to identify the advantages of using VSM (Abdulmalek and Rajgopal, 2007). Note that the integration of VSM with DES is more prevalent in manufacturing than in the construction industry. Simulation-based VSM makes it possible to analyze complex systems and communicate the simulation results in a language that lean recognizes (Solding and Gullander, 2009). Both VSM and DES provide a holistic view of a system, but DES adds a fourth dimension, time, to VSM. The combination of DES and VSM offers insights that may have been missed if VSM alone had been used (Donatelli and Harris, 2001). Thus, DES can enhance VSM.

An integrated Value Stream Mapping Framework

Our literature review reveals that lean methods and process simulation are being increasingly adopted. However, applications in construction are still limited, even though they have been considered (Agbulos et al., 2006, Lu, Olofsson, & Segerstedt, 2010). More importantly, there is a lack of an integrated approach that may provide a way to compare the performance of the lean system to that of the existing system (Detty and Yingling, 2000).

This approach may be especially important for SMEs that have limited resources and where implementation of unsuitable solutions can be detrimental to the company. This is demonstrated by a case study of the roasted and ground coffee industry, where combining VSM and DES enabled the improvement of the SME's batch production system (Parthana and Jirachai, 2012). The proposed framework integrating DES and VSM (Figure 1), based on the literature review, thus presents a systematic description on how SMEs may use these two approaches to reduce the risks by simulating and visualizing the future VSM before implementation. McDonald et al. (2002) described how an integrated application might also be able to predict the outcomes of dynamic situations that could not be addressed by VSM alone.

After the initial step of mapping the current state, the workflow is divided. DES and VSM are carried out in parallel. To build a DES model, the "model conceptualization" step abstracts the essential characteristics of a production system and formalizes the mathematical and logical relationships of the components in the DES model. Data can be collected by observations, interviews, workshops or archival documentation. The DES model developed is verified by tracing entities to determine if the model's relationships are correct and accurate enough. During verification, the performance of the simulation model is compared with the existing system, but also visualized together with

practitioners, in order to validate the DES model. Visualizing construction operations in a 3D environment can be of considerable help to the validation of simulation models and provide valuable insights into the details of construction operations (Kamat and Martinez, 2003).
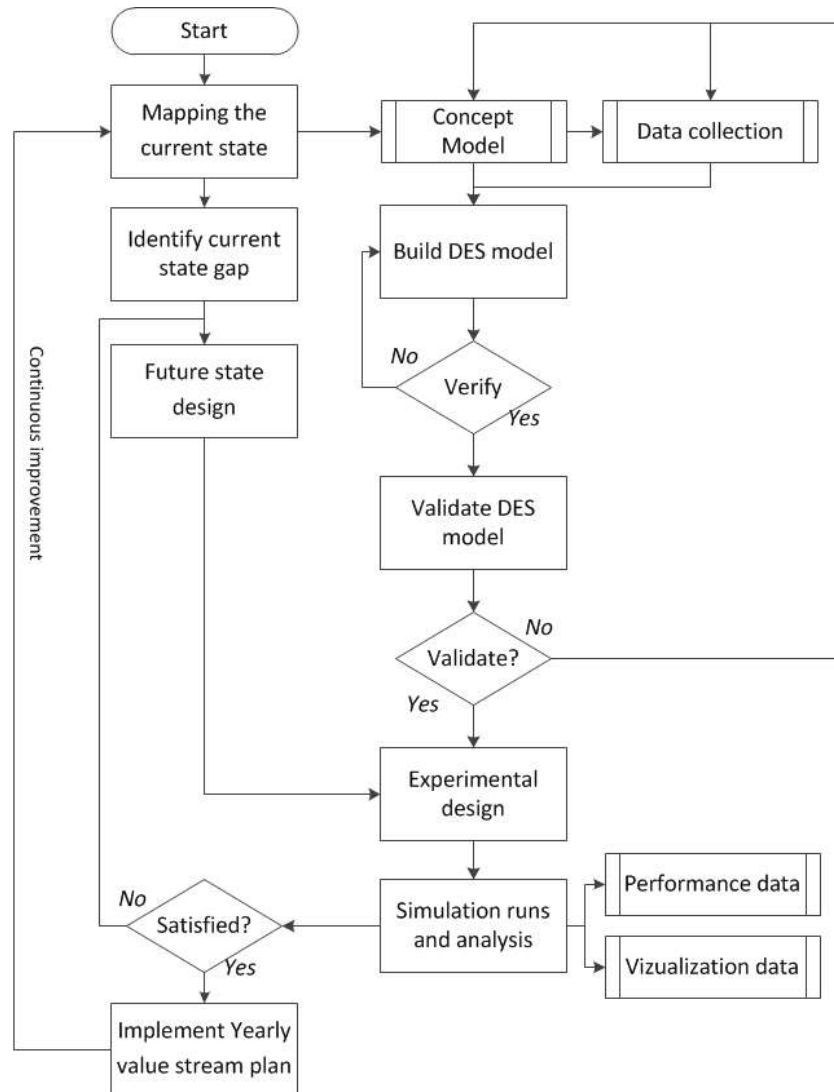

Figure 1 A proposed framework integrating DES and VSM and their interrelationships based on the literature review

The validation of the simulation model, through visualization of the construction operations enables the simulators and managers to walk through the virtual environment step-by-step to determine whether the simulation model behaves as determined by the future VSM, as shown in figure 1. If problems are identified, the process returns to the steps "concept model" and "data collection". At the same time, the VSM helps to "identify current rocks" using the Japanese lake analogy, and remove them, i.e. non-value adding activities, generating the next future VSM. The VSM and DES workflows are merged at the "experimental design" step integrating the static VSM and dynamic DES, to produce 'hard facts' about proposed changes. DES is used to evaluate and validate the expected

outcomes of the different scenarios i.e. the behavior of the future VSM. If the outcome is the desired, the future VSM can be implemented in order to increase system performance.

Case Study

The supply chain for industrialized construction companies in Sweden is made up of many small companies that have fewer than 250 employees and a turnover below € 50 million. To validate the proposed framework for the integration of DES and VSM, a qualitative case study of a construction component manufacturer was chosen, because of the company's position in the industrialized construction supply chain. The case study company produces windows, patio doors and other components for industrialized builders of detached family houses. The case study examined the value stream from the receipt of the raw materials to the delivery of patio doors to Sweden's largest industrialized house-builder, which has about 30% of the total market share. A total of eight different patio door models ordered over 42 months showed little variability, with an average of 188 doors per month. The demand followed a seasonal variation that is normal in construction, with higher demand during the summer months. The data collected in relation to the proposed framework are shown in Table 2.

Table 2: Sources of data obtained during the research.

Data Collection method	Purpose	Note
VSM Workshops	Input for the VSM and simulation model conceptualization	Transcribed comments from three workshops with the managing director, production manager, and marketing manager. The current and future states were drawn in Visio (Erikshammar et al., 2010)
Interviews	Validation of DES model Understanding the SME challenges Validation of the implementation	Transcribed semi-structured interviews with the managing director, production manager and marketing manager
Archival documents	Validation of VSM model	Triangulation of VSM results with workers' time sheets and financial calculations
Transpose validated data from VSM to DES	Simulation data	Data from each production process step were compiled into spread-sheets and then used as input
Simulation runs	Experimental data	The simulation was run at the university and the results validated with the practitioners

The company faced two major challenges in their current batch-oriented system:

- How to increase flexibility in the production system?
- How to reduce lead time to customer without increasing inventories?

In order to strengthen the validity of the case study, the respondents were given an opportunity to verify the accuracy of the transcribed interviews (Table 2). The validity was also strengthened by the triangulation of VSM results, simulation and archival documents of the current system behavior. Participant observations during the data collection provided the researchers with the opportunity to compare qualitative data with measured and simulated data and thereby build a reliable simulation model. For the VSM and DES applications, lead time was used as the controlling parameter. The relationship between lead time and work in progress (WIP), or buffers, is linear, as defined by Little's Law.

Research Findings

The research findings are presented by describing the steps in the framework for integrating VSM and DES as shown in figure 1: Mapping the Current State and Identify Current State Gap, Future State Design, Experiment, Simulation Runs and Analysis, and Implement Value Stream Plan.

Mapping the Current State and Identify Current State Gap

Preparation started with discussions with the managing director. These were followed by the first workshop with the managing director, the production manager and an operator to obtain detailed knowledge of the production process, machines and staff. In this first workshop, the Lean philosophy and Lean tools, with a focus on VSM, were presented. The second workshop, lasting three days, was held at the plant where the VSM team and researchers walked through the production flow, from receipt of raw materials to finished goods, to gain an overview of activities and to interview personnel. Then, a map of the current state from start to finish was constructed using post-it. The result was transcribed (Figure 2) using VSM notation (Rother and Shook, 2003).

The current VSM (Figure 2) represents a push system. To use the planing machine as often as possible, parts are pushed onto the production line when it is idle. As raw material was delivered once a month to the factory, there was a monthly production schedule that controlled fabrication. Material was stored for an average of 10 days before it was planed. In the next process step *Working*, holes were drilled for mounting the espagnolettes, arcs and hinges. The *Filler* step was where quality defects in the assembled components were manually filled and repaired before moving onto the *Priming* and *Painting* steps. After the paint had dried, the hinges were mounted and the patio doors were *assembled* and packaged, eight doors per pallet, ready for a weekly dispatch to the customer. The current state showed the following issues that needed to be addressed:

- Demand for a whole month's worth of production batches, simultaneously released into the production system, caused the production area to become filled with material and pallets, creating a risk of mixing-up orders and causing defects
- Total lead time was longer than the demand horizon which resulted in decisions being made based on forecasts rather than actual demand, thereby reducing flexibility

- ▪ Waiting time caused personnel to start the production of other orders leading to even more WIP

It is logical for the company to produce a whole batch after setting up the planing machine, since changing the die (set-up time) takes up to twelve hours. When there is high customer demand, the company needed to put at least the whole monthly batch into production in order to be able to use the planing machine for other orders.
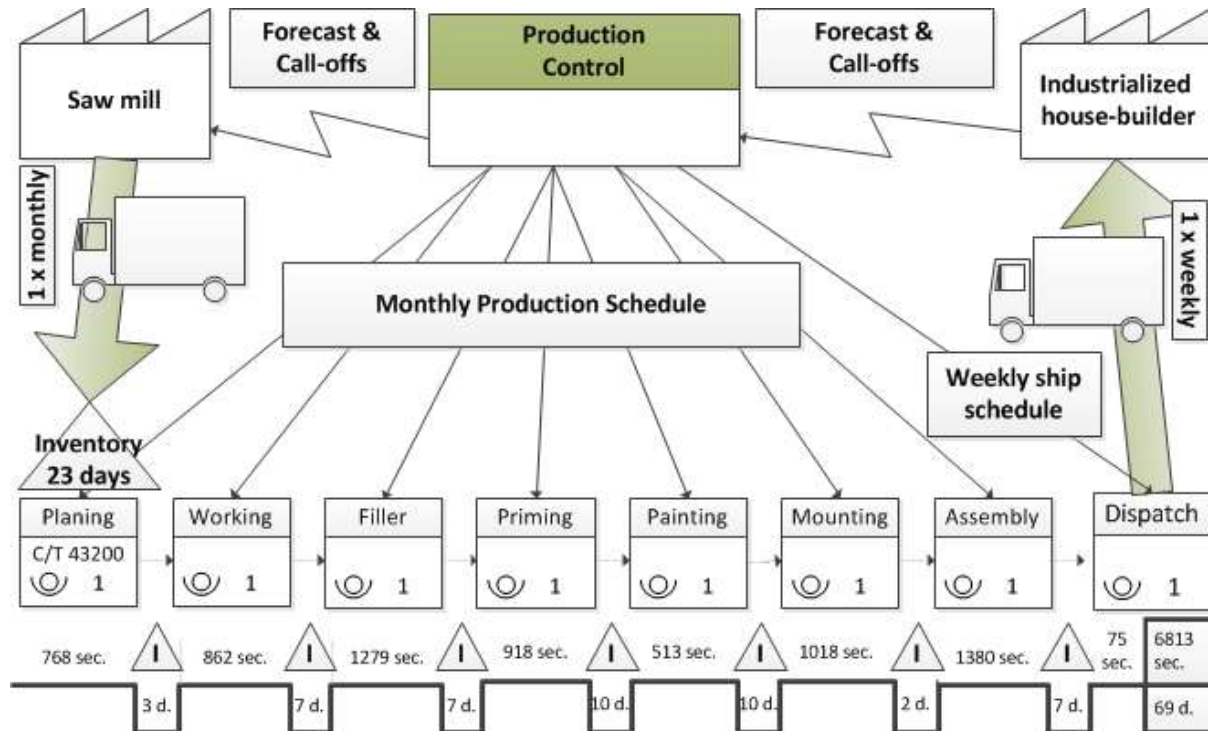

Figure 2 Illustration of the current state VSM as transcribed from the workshop.

Future State Design

A workshop and brainstorming session was then held, considering the question: "how would you change the production process to make it world-class and what would the production process look like in 10 years"? The ideas were put on a white-board using post-it notes and later transcribed into a diagram of the future state (Figure 3). The team suggested a future state design with the following improvements to reduce lead time and increase flexibility:

- • Reduce the customer batch size to a two-week batch
- • Create a small finished goods inventory in order to level out the demand
- • Introduce takt time

The Introduction of takt production time means that the resources, except planing, work 6 hours per day, with a two week batch of 192 items being pushed to the production system. The initial inventory at the decoupling point is 96 doors. This means that the planing machine is set-up twice a month instead of monthly. This increases the process time at the planing, but currently the planing machine is at times in the month and so an increase in the number of set-ups will not affect the capacity. This process can be followed until there is a technical solution for reducing the set-up time of the planing.

Painting is now a collection of activities put into a production cell along with filler, priming and painting, in order to reduce set-up and cleaning time and also to reduce the need for a buffer. The working operation has also been designed as a production cell with one piece flow. Before the working operation, the buffers act as the interface between push and pull, that is, a decoupling point with a supermarket solution. On every Friday the actual number of doors ordered, 48 doors on average, is dispatched to the customer.

The current and future VSM were displayed where everybody in the factory could see them and a team was assembled to start the implementation. However, the implementation phase was paused when the managing director said at one meeting:

> *"I can see it, I can believe it, but how can I be sure that these improvement strategies will benefit us and not plunge us into chaos"*
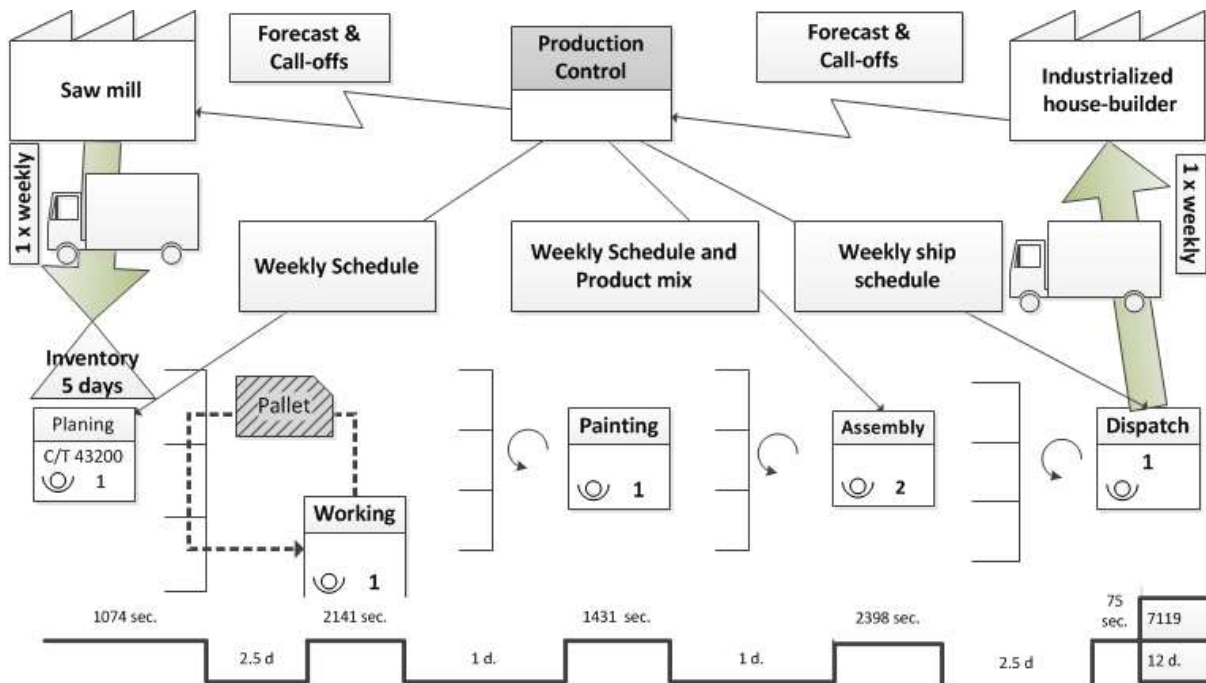

Figure 3 Illustration of future state VSM from the initial workshop.

Experimental Design and Simulation Runs

The integrated model was built according to the framework to integrate DES and VSM, as shown in Figure 1. The simulations were carried out using SimioTM, a simulation modeling framework based on objects which supports both discrete and continuous systems, along with large-scale application, and is s based on agent-based modeling (Sturrock and Pegden,2011). The simulation workflow starts with a model for the current VSM which is verified and validated in two ways. Then, the model is modified to reflect the proposed future VSM and assess the impacts of adopting it.

The DES was carried out at the same abstraction level as the VSM. The inputs to the model were: (a) patio door variants, (b) customer demand, (c) process and waiting time

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and (d) production and transportation batch. The output from the simulation model was a production summary (Figure 4).
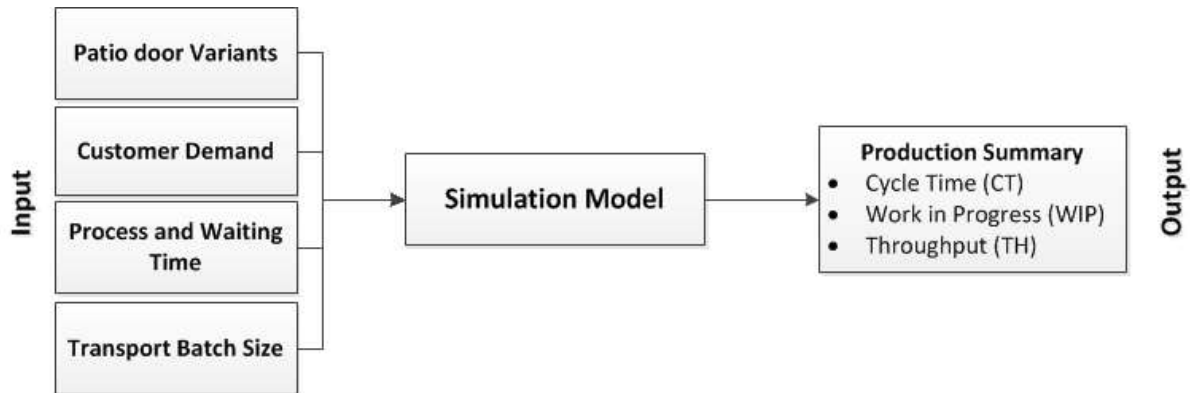

Figure 4 Input to and output from the simulation model.

Validation of the future state design is simulated by using a strict takt time production cycle to enable an even flow, which means that 12 components have to be produced by each workstation every day from Monday to Thursday. The company uses a capacity buffer, i.e., the use of more workers and/or overtime to complete the takt time production cycle if necessary. Lead time and batch sizes are the same.

The simulation run time is 120 weeks. Warm up time is 4 weeks. We define the input data (Table 3) of the simulation model thus (Hopp and Spearman, 2000):

- Cycle time (CT): the average time from the release of a job until it reaches an inventory point, that is, the time the part spends as WIP.
- Work in progress (WIP): the inventory between the start and end points of a product
- Throughput (TH): the average output of a production system.

Table 3: Input data of simulation model.

	Planing	Working	FillerGrinding	PrimePainting	TopPainting	MountHinge	FrameFinalAssembly
Operation time per unit (seconds)	Normal (600,100)	Normal (1098,100)	Normal (1392,108)	Normal (1026,100)	Normal (579,115)	Normal (629,125)	Normal (1152,130)
Set up time per batch (seconds)	43200	450	0	900	900	600	900

The simulation model is verified using two approaches. First, a trace window is used to check the intermediate simulation outputs, as shown in Figure 1. Second the simulation response is compared with a known analytical solution (Kleijnen,1995). In the simulation model, a state named WIP is defined to represent the work in progress in the system. The initial state value of WIP is set to 0, but when an order is moved to Machine planing, the value becomes WIP=WIP+1 and when an order is completed in Machine Frame final assembly, the value becomes WIP=WIP-1. In the final assembly process step

(FrameFinalAssembly), the cycle time and time between jobs out are measured. These two values are used to calculate the average WIP using Little's law (WIP=TH*CT). The calculated value of average WIP is compared with the state value of WIP calculated by the simulation model. If they are almost the same, then we can verify the simulation model because the simulation results are consistent with Little's law. From the statistics of the simulation model, the average CT is 345.65 hours and the average time between jobs out is 3.47 hours. The calculated average WIP by Little's law is 99.58. The average WIP calculated by simulation model is 98.76. These two values are almost the same. Hence, by comparing with the average WIP from the simulation model, the simulation model has been verified.

Table 4: Output data of simulation model.

	Mean cycle time (hours)	Std. Deviation cycle time	Average WIP
Current VSM	345.65	142.57	98.76
Future VSM	246.75	79.84	23.05

Simulation of the current and future states shows that lead times are reduced with reduced batch size, as expected. Mean inventory level, converted using Little's law to units of time, is reduced when using reduced batch sizes (Table 4). The total time for processing one door, as defined by the future state design, is actually less than that in the current state, enabling just-in-time delivery of weekly orders. This means that the company would have a shorter lead time to the customer in the future with reduced inventory. The total number of finished goods is reduced. The reduction of lead time as defined by the future state design can be achieved by a reduction in the production batch size to an equivalent of one day's worth of average customer demand.

Usually, statistical analysis is needed to determine whether observed differences are due to differences in system designs or to the randomness inherent in the simulation model (Banks et al., 2000). In order to better understand the effects of the changes proposed on the future state map, a Two-Sample T-test was carried out. The statistical analysis was carried out using Minitab. The outputs (Table 5) indicate a large difference in lead time when comparing the current VSM with the future VSM. Hence, the significant difference between the current and future VSMs can be concluded to be due to the different designs.

Table 5: Output data of simulation model. Estimate for difference: 98.90, 95% CI for difference: (95.15, 102.65) and T-test of difference = 0 (vs not =): T-Value = 51.72 P-Value = 0.00 DF = 11453

	N	Mean	StDev	SE Mean
Current VSM	7296	346	143	1.7
Future VSM	7317	246.7	79.8	0.93

Value Stream Plan Implementation

The future state VSM was transformed into the activities that made up the yearly value stream plan. All activities had a person responsible for them and the production manager was appointed as the value stream manager. After the simulation results were presented at the final workshop with the managers and the production staff present. One of the staff stated:

> *"I knew that something was wrong when the harder we worked the less we produced"*

During an interview, the manager stated that the simulation data could also be used for estimating the cash-flow (finished goods inventory) and the level of workforce required. In this way, the production manager could show the managing director how a reduction in batch sizes (reduction of inventory) would affect productivity (maintaining or improving it) and mean order delivery time (at least maintaining the status quo). After the simulation results were presented, the managing director gave the 'go-ahead'.

A year after the final workshop an interview was conducted with the managing director. The future state design was not fully implemented because:

- The demand from the house builder had reduced by more than half due to the economic recession and because a larger part of the orders were now custom ordered for each project (unique orders).
- The design of the patio door changed due to new energy regulations and operationalizing the finished goods inventory was postponed until the new product has been certified.
- The production cell of 'working' lay out had changed. The machines had been re-designed to be more flexible. This increased the set-up time and therefore the supermarket is positioned after the working operation.
- Due to low demand, the painting operation was only carried out for 2 days a week instead of 4 hours per day for this product.

However, by using Make-to-Stock production strategy for the patio doors and Make-to-order production strategy for unique project orders, a better flow was achieved.

Analyzing the Integrated Framework

According to Lean principles, process improvement is often implemented using continuous improvement (*Kaizen*) or radical change (*Kaikaku*) strategies (Imai, 1986). The crucial prerequisite for these strategies is a standardized process in a defined system. In the absence of a known standardized process, the improvements require process mapping, where key problems in the current process are identified. The last step is to design and implement the new process, based on validated data, with appropriate methods. The unit of analysis is the proposed framework of integrating VSM and DES and therefore it is relevant to analyze the framework and its components based on literature review.

The framework for integrating VSM and DES uses VSM to identify potential future improvements and uses DES to provide a quantitative evaluation of the proposed improvements. By providing "hard facts", the proposed implementation of the future state

design passed through the management gate in the stage gate process. As described by Gurumurthy and Kodali (2011) and Anand and Kodali (2009), this gave the management the opportunity to understand the future state production process design and performance. The framework supports the idea of providing the manager with more analytical data to reduce the uncertainty (Forsman, 2011). The evaluation of the solution through discussions (Daft, 1986) between experts, the production manager and the managing director resulted in a better understanding of the system dependencies, something that the framework encourages. The interaction probably also reveals the process of finding the right questions to ask (Levander, 2011) and therefore to simulate.

This underlines the idea that simulation can be used to reduce the iterations of more costly real-world implementations as described by Abdulmalek and Rajgopal (2007). In fact, the findings show that the framework is iterative rather than sequential, hence the need to validate the conceptual model and re-collect data several times. This is consistent with the case study described by Agyapong et al (2009).

Table 6: Gap and selected improvement strategies suggested by the Future state design using VSA, Future state Validation using DES and Implementing the Value Stream Plan.

Gap	Future state design using VSA	Future state Validation using DES
Increase production flexibility using the current batch-oriented system	Reduce batch size of raw material to 15 days, weekly batches in production	Reduce batch size to weekly deliveries of raw material and daily batches in production
Reduce lead time without increasing the finished goods inventory	Release weekly increments	Release daily increments

The static model VSM, even when using spreadsheets for analysis, could not:

- Predict the effect of variability in the production system of events such as the level of customer demand when assuming a normal distribution of their occurrences.
- Consider the effects of random variation in processing times and customer demands

By adding the component 'experimental design' the researcher and the management found common ground in a systematic approach for 'what if' scenarios. It has also been shown, for example by Marvel (2009), that the simulation model could anticipate the behavior of the system, thus making it possible to fill the gaps more efficiently (Table 6). In order to increase the confidence in the model it needs to be both verified, that is determining that a simulation computer program works as intended, and validated, that is determining whether the conceptual simulation model is an accurate representation of the system, as described by Law and Kelton (1991) and Agyapong et al. (2009).

These are the questions that the managing director wanted answered before giving a 'go-ahead' for the implementation. The managing director could use experience to translate the proposed changes into anticipated cash-flow savings with the necessary management practices. Use of the simulation model helped the value stream manager and

the managing director to assess and quantify the future state design instead of using a trial and error method for improving the production system in a way similar to that described by Yu (2009) and Gurumurthy and Kodali (2011). This means that there is a need to analyze quantitative data using experimental design before implementing the yearly value stream plan and therefore support the framework and the interrelationships between the steps described in that framework.

The notion of making continuous improvements by looping from the last step back to the first step in the framework is supported by the literature. This means that the variability of the system is changed and the possibility to discover new, undiscovered rocks is possible. This means that system variations can be discovered and incorporated into a new reliable, validated model of the new future state.

Discussion and Conclusion

We have developed and validated the framework for integrating VSM and DES, which makes it possible to improve the production process performance in industrialized construction. By the use of a case study, we have tested the use of VSM enhanced with DES: an improvement of the production process can be verified and thereafter implemented. This framework gave the manager at a small company the opportunity to verify outcomes before proceeding with improvement strategies. The analysis shows that it is reasonable to assume that this integrated framework helped the management make decisions based on rich information.

An additional benefit of the integrated framework is that the manager had time to understand the problem description and the suggested solution. Situations such as random variability in customer demand are often overlooked when using VSM but are considered in the validation step of a DES. The presence of expertise also helped the manager to focus on another way of working. Small businesses tend to think in the short-term, focus on operations and react in a more intuitive way to situations rather than using analytical data.

The integrated framework makes it possible to validate VSM solutions analytically and compare current state designs with future state designs with respect to throughput, inventory and/or operational costs. In general, this implies that improvement strategies for production processes in this sector would benefit from the proposed framework. The framework needs to be further developed to define interfaces and the interrelationships between the different framework steps.

Assuming that there is a seasonal variation in customer demand, this simulation model is valid. Here, a seasonal variation in customer demand means that the demand from the customer can vary over time, across seasons, but does not have a large variation over a shorter time unit (e.g., month). If this is true, the simulation model should be valid in a construction setting and therefore it is reasonable to assume that the framework is also valid in this setting. However, in order to provide greater generalization, the framework should be tested using a seasonal variation of customer demand that differs from the situation for a small supplier in the industrialized construction environment.

The benefit of the suggested framework, which itself is not an analytical model, is that it integrates the need for consensus building and understanding with the need to provide analytical data for rational decision-making, using VSM.

Despite its obvious advantages, the use of DES in the construction industry has mainly been limited to the academic community. Building and analyzing a DES model is still time-consuming and needs skilled professionals, the cost of which can be prohibitive to SMEs. Future research will explore the development of a VSM-oriented simulation template for use by SMEs that encapsulates the simulation programming code. The reusability and parameterization of the VSM-oriented simulation template will provide SMEs with the ability to quantitatively evaluate whether a VSM-based improvement would be possible.

However the time between the actual implementation and the time to build the model was stretched somewhat, since it was shown that the real world changed due to the economic recession and different product requirements caused by various factors such as in this case new energy regulations. Also, there was a change of factory layout in order to handle other orders, because demand from the house builder was heavily reduced. There is a need to speed up the process between model conceptualization and model validation.

Acknowledgments

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