Addressing the challenge of lean manufacturing sustainment with system dynamics modeling: a case study on apparel manufacturing in a developing country

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Abstract

Lean techniques have yet to extend to the majority of manufacturers in developing countries where traditional work practices are dominant and cultural resistance to change is high. This research consists of a case study about a Lean implementation at a clothing manufacturer in a developing country. Production wastes are identified and appropriate lean techniques, namely Total Productive Maintenance, Kanban and Supermarket Pull, are used to eliminate or reduce them. The potential impacts on the manufacturing system are first assessed using a system dynamics model. The modeling results showed that system performance, in the form of reduced work-in-process, is improved by 34% on average starting immediately after the lean intervention, which was replicated by a similar trend in practice. A similar improvement trend was achieved with the actual implementation of the selected lean techniques. And since lean improvements are typically difficult to sustain over the long term, the system dynamics model is simulated over a 6 months period to ensure the achieved benefits are sustained.

Keywords
Lean Manufacturing; System Dynamics; Apparel Industry; Kanban; Lean Sustainment

1. Introduction

The worldwide fashion industry is one of the most competitive sectors of the global economy where a vast number of manufacturers compete without geographic boundaries, producing countless product varieties at an extremely fast pace, and for smaller and smaller profit margins. In such an environment, efficiency has long been a must, making the use of process improvement methods essential at all levels, from production operations to supply chain management. Lean manufacturing is one of the most popular methods for continuous improvement across all stages of a production operation, focusing on minimizing wastes in production time and effort, and maximizing productivity such as production throughput and product quality. However, one of the biggest challenges facing lean success is sustaining the performance improvements over the long run (Rymaszewska, 2014) due to a variety of problems. Some of these problems are well known, such as cultural resistance to change (Oudhuis and Olsson, 2015) and the lack of management commitment to lean (Salge, 2008), but other problems are unpredictable and are due to the complexity of large-scale manufacturing systems. Such problems are best understood with the use of systems thinking and system dynamics (SD) modeling, especially when the purpose is to identify the problem and its root cause rather than to patch up the visible negative impacts (Meadows, 2008). The use of system dynamics to model lean manufacturing operations has had little attention in the literature. In this work, an actual lean implementation is conducted for reducing work-in-process (WIP) at a children's apparel manufacturer in a developing country. The manufacturer experiences internal inefficiencies due to management and production problems, and external challenges in the form of fluctuating demand. In this study, an SD model of the production process is developed in order to simulate the impacts of complementary lean techniques on system performance over the long-term. The performance of the implemented lean improvements was monitored over a period of 3 months in order to ensure the improvements are sustained.

What differentiates this study from previous work is in using SD modeling for assessing the performance of an actual lean implementation effort involving a variety of complementary lean tools in a real-world context, whereas previous studies have modeled mostly hypothetical manufacturing operations in order to investigate the impact of a single lean technique. In addition, the developing country context of this study provides an opportunity to identify significant challenges facing lean sustainment over the long-term because in this context resources are typically much more limited, management much less committed and work methods much less organized than in the industrialized world.

The rest of this paper is structured as follows: Section 2 presents an overview of the recent literature on system dynamics modeling of lean manufacturing implementations. Section 3 details the research methodology. Section 4 is a description of the current state of production operations, and Section 5 describes the implementation of the lean techniques and the use of system dynamics modeling to assess the impacts of lean improvements in the future state. The results are reported and discussed in Section 6 in terms of reduced work-in-process (WIP) and improved productivity. Concluding remarks and proposed directions for future research are reported in Section 7.

2. Literature review

There has been a recent increase in the number of published studies using the system dynamics method to model manufacturing systems and supply chains for a variety of purposes ranging from the design of sustainable manufacturing systems (Zhang et al., 2013) to the management of disruption risks in an integrated supply chain (Gu and Gao, 2017). This increased attention is based on the wide realization by academics and practitioners alike that manufacturing systems are increasingly complex, and that process modeling and simulation are valuable tools to deal with such complexity in a cost-effective way.

However, the body of literature combining the use of systems thinking with lean thinking in manufacturing remains very small. This is perhaps due to the still overlooked fact that systems thinking can help to overcome lean implementation failures in practice, as will be demonstrated in this study. This is because systems thinking facilitates the tracing of problems to their actual root cause, avoiding the narrow focus on individual processes in favor of a full systems view (Hofmann and Powell, 2012).

A number of studies have been recently published addressing the development of system dynamics models to assess various aspects of lean manufacturing (Ali and Deif, 2016; Omogbai and Salonitis, 2016; Rodrigues et al., 2013), with the majority of studies looking at performance impacts (Elmaraghy and Deif, 2014; Omogbai and Salonitis, 2017), and a few proposing conceptual frameworks for dynamic modeling in this context (Drews et al., 2016; Godinho Filho and Barco, 2015). However, these studies remain limited in number and scope. This is why several of them have already advocated for more attention to dynamic modeling in the lean manufacturing context.

A review of the objectives of these studies reveals that only a few report on actual lean implementation initiatives on the factory floor (Omogbai and Salonitis, 2017; Pai et al., 2013; Rodrigues et al., 2013), while the vast majority uses SD to model hypothetical lean improvement scenarios, rather than to simulate the potential outcomes of an implementation event based on real data. The former approach produces generic results not tied to a real context and can only lead to general recommendations. The latter approach, adopted in this study, leads to specific results and allows the selection of appropriate policies and strategies for process improvement. This makes the contribution of this work more meaningful, especially that the lean implementation is done in the context of a developing country, something that very few studies have tackled. This is important because context in this case can drastically alter the dynamics of the modeled operations.

It is also observed that not many lean techniques have been considered in the literature, with only one study combining the use of several lean techniques in the system modeling (Elmaraghy and Deif, 2014), as is done in the current study.

3. Methodology

This study consists of an actual lean implementation at an apparel manufacturer of children's clothing located in Lebanon, a developing country of the Middle East region. The manufacturer is a family-owned business with a medium-sized factory operating with mostly non-lean manufacturing methods and a traditional work culture. The product mix is very high due to different clothing model varieties. The manufacturer experiences variable demand on a monthly basis, and there are seasons of high and low demand.

The research was conducted in accordance with the principles of lean implementations (Feld, 2001), which consist of an assessment of the current-state of production operations and a definition of an improved future state using value-stream mapping. Semi-structured interviews were used to gather information about work methods from line workers, and unstructured interviews were conducted with management to develop an understanding of the work culture at the plant (Robson, 2002). Process times, WIP and demand data were collected over a total period of 3 months in order to build a detailed system dynamics model of the entire production process.

4. Description of the current state

A value-stream map (VSM) of the current state was developed, as shown in Figure 1, identifying all stages of the production process and the corresponding wastes.

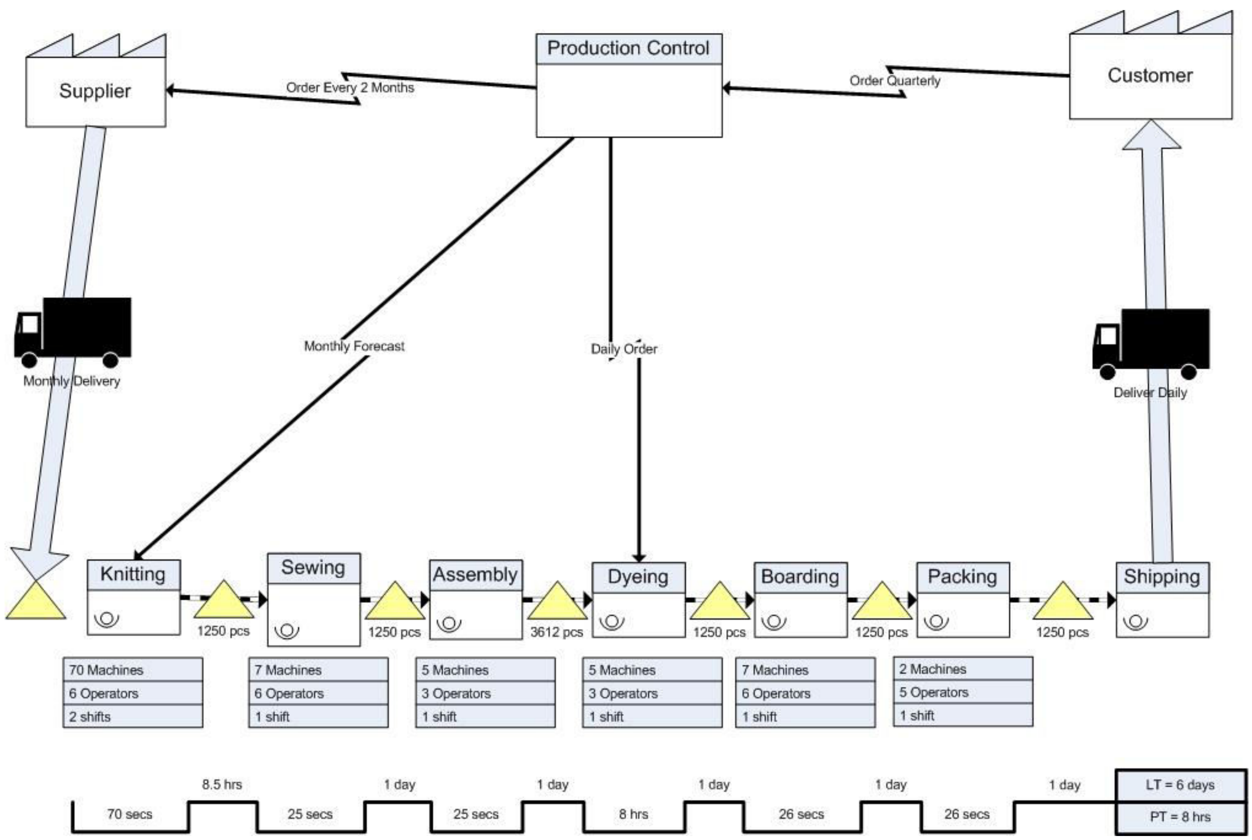

Figure 1: Current state VSM

As shown at the top of the figure, the manufacturer receives customer orders according to a 4-month forecast, but actual demand almost always fluctuates. Accordingly, production control requests raw materials from suppliers located abroad, and sends a monthly production schedule to the Knitting department where product manufacturing starts, along with a daily schedule to the Dyeing department where the product is given its final color as per the customer's order. The current production strategy is to utilize all machine and worker resources to produce the target output. This reflects a traditional "economies-of-scale" mentality where production throughput is maximized in order to minimize unit cost, regardless of actual customer orders. This makes the first process upstream "push" items downstream whether the next process is ready for them or not, which creates WIP inventories at all stages of production.

In addition, management policy is to maintain an inventory worth an entire day between departments as a buffer stock. Specifically during the period of this study, WIP is pushed from the Knitting department at an average rate of 1250 pieces/day every 24 hours, which is maintained as buffer inventory between processes, as noted with inventory triangles on the VSM.

Any machine breakdowns or sudden surges in demand lead management to pressure the workers to make up production gaps during regular hours to avoid overtime pay, creating a stressful environment and causing high rates of worker absenteeism in the following days. At the sewing and assembly departments, WIP inventories are typically larger than the buffer due to frequent machine breakdowns, which itself reflects the lack of preventive maintenance and leads to relatively high rates of defects. A higher inventory of approximately 3600 pieces occurs in the Dyeing department, as arriving items must be held in waiting until the required machine load capacity is reached for dyeing all pieces at once. The items are then boarded to be ready for packing the next day, and then delivered to shipment the day after.

In summary, four of the seven wastes of lean were observed in the current state, namely overproduction and inventories at all stages of production, waiting at the Dyeing department, and product defects especially at the sewing department due to lack of machine maintenance. Chronic failures in meeting production targets were observed due to the noted wastes.

To understand the dynamics of this production system, an SD model was built using the software Vensim (Ventana Systems Inc., 2013) representing the production process captured in the current state VSM, as shown in Figure 2.

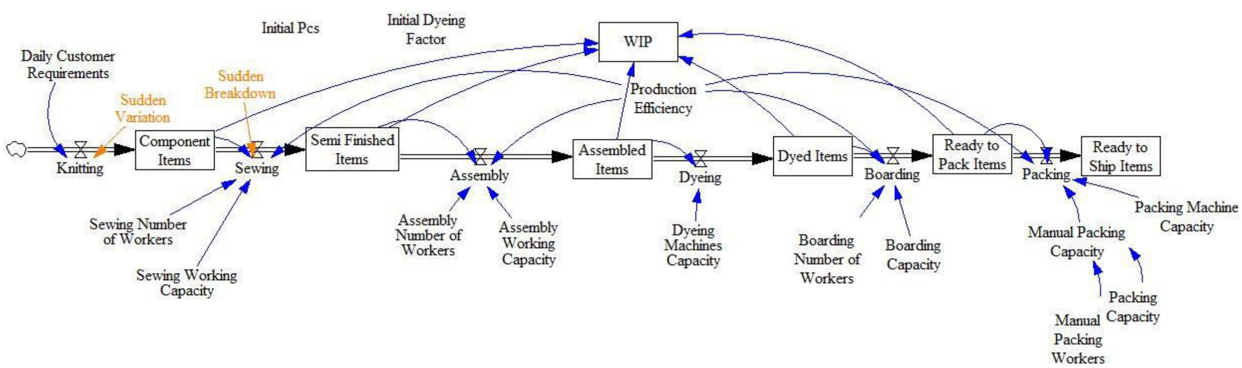

Figure 2: SD model of the current-state production process

Customer demand was obtained from company historical data over 2 years, and the probability distribution function with the best fit was found to be the random normal distribution, bounded between observed values of 1,100 and 1,400 pieces, with an average equal to the buffer size. WIP inventories at each stage of production are modeled as stocks, with flows representing the actual processing in between stages. Affecting each flow are auxiliary variables representing the number of workers on each machine, the machine's throughput capacity, and an overall production efficiency factor which reflects worker absenteeism and machine breakdowns. The current value of production efficiency at the plant was calculated at approximately 80%.

In order to further capture the occasional major disruption in production, a breakdown scenario was included in the model using a pulse increase in demand of 250 pieces at day 13, followed by a sudden stoppage of all sewing machines for 24 hours at day 30. This causes a significant increase in WIP at all stages of production, flooding the system with products waiting further processing, as was observed on occasion in the real system. All WIP are accounted for in a single stock (Total WIP) to monitor the total inventory level at the plant throughout the simulation.

The SD model was validated to ensure it is able to reproduce the actual behavior and performance of the production system (Barlas, 1996).

5. Description of the lean-improved future state

Based on the current state VSM, it was decided to focus on reducing WIP at each stage of the production process, in addition to eliminating or reducing the other types of waste identified in the current state assessment, using appropriate and complementary lean techniques.

The main chosen techniques were Kanban and Supermarket Pull to reduce WIP, and Total Productive Maintenance (TPM) to tackle the defect waste. The 5S lean technique was also used to reduce waiting at the Dyeing department by organizing work tasks, sorting equipment and setting the workspace in order.
Starting from the Dyeing process and moving up the value stream, a Supermarket Pull system was used to reduce the excessive WIP inventories resulting from push production. Using the recorded daily demand and an estimated operator processing capacity of 300 pieces per day, the supermarket was sized to hold 4 containers of 300 pieces each, and a corresponding 16-container Kanban system was established between the upstream processes as shown in Figure 3.

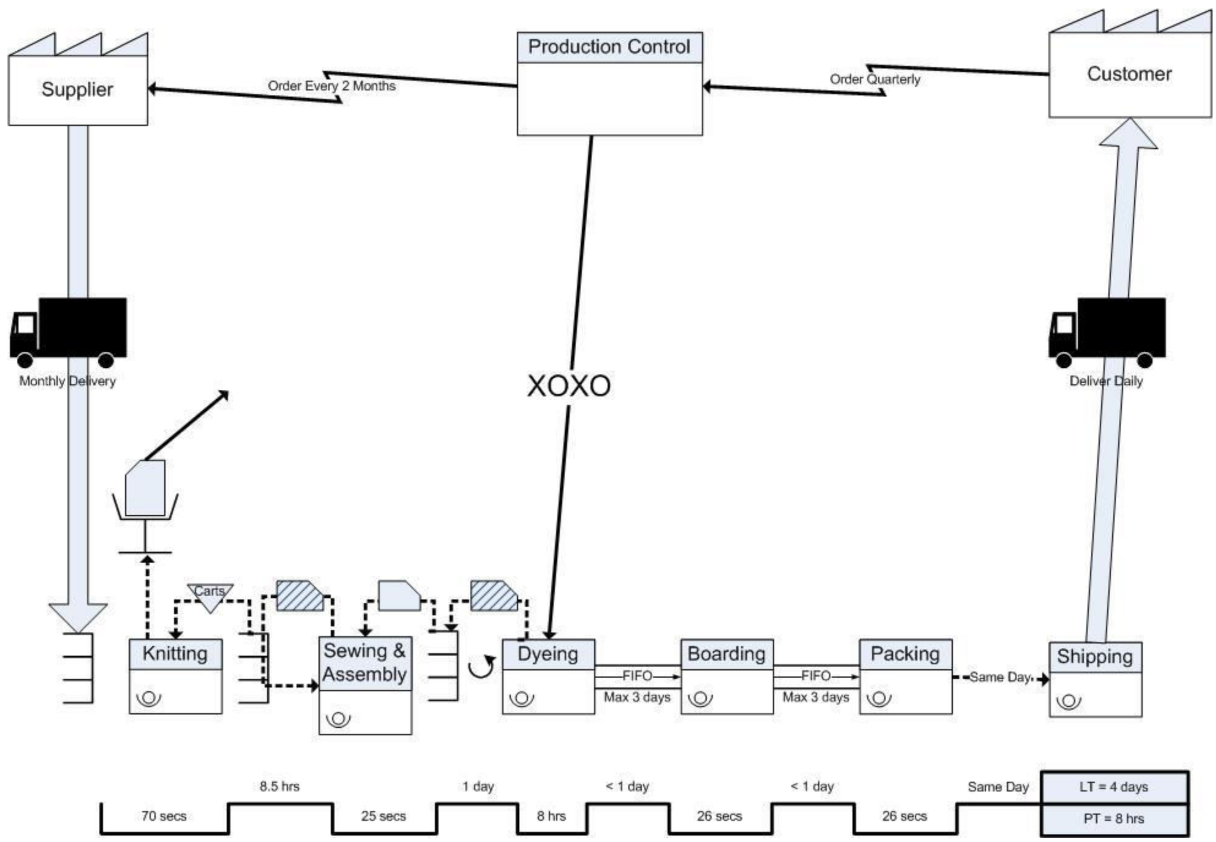

Figure 3: Future state VSM

In the lean improved state, Production Control sends a weekly production schedule directly to the Dyeing department as per a weekly customer forecast, providing instructions for pulling products from the Supermarket using the Kanban containers. Once items are removed from the Supermarket, the Sewing and Assembly department retrieves the empty container and replenishes it, sending a full container back. Downstream of the Dyeing process, a first-in-first-out (FIFO) lane was established with a maximum buffer of 3 days to synchronize with downstream processes, ensuring delivery of items from boarding to shipping on a daily basis.

Sewing and Assembly are now joined into one production cell with the same cycle time since applying TPM reduced the high rates of sewing machine breakdowns and made it possible to sew and assemble at the same time. In turn, the new Sewing and Assembly process pulls items from the Knitting supermarket through the Kanban system, and information of what is being pulled is sent back to Production Control to provide an overview on production progress.

Figure 4 shows the SD model of the future state with feedback relationships between every process and its predecessor, representing the appropriate lean intervention at each production stage. The "Gap" variable in the model compares actual WIP in the system with a new target total WIP of 5000 pieces/day (the sum of all buffers in the production process) as a maximum ceiling, and triggers the lean intervention in the production system as soon as the limit is exceeded. In other words, the Lean intervention is needed to counter the current management policy of holding unnecessary buffer inventory between processes.

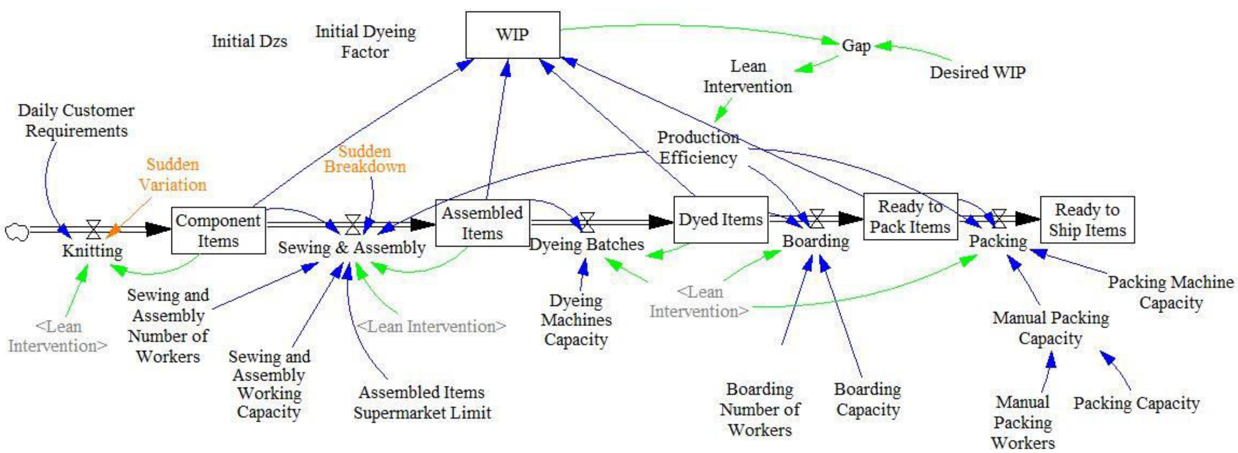

Figure 4: SD model of the production process post-lean implementation

Once the SD model was simulated and the impacts of the lean techniques were quantified, the lean techniques were applied in practice, taking approximately 8 weeks to implement. The result of the lean implementation was a significant decrease in the total WIP similar to that observed in the model, along with a damping down of the impacts of sudden disruptions, as discussed in the following results section.

6. Results and discussion

The impact of initiating lean on the production floor reduced unnecessary WIP between processes being used to make up for poor maintenance and production inefficiencies. The results of the simulation are shown in Figure 5.

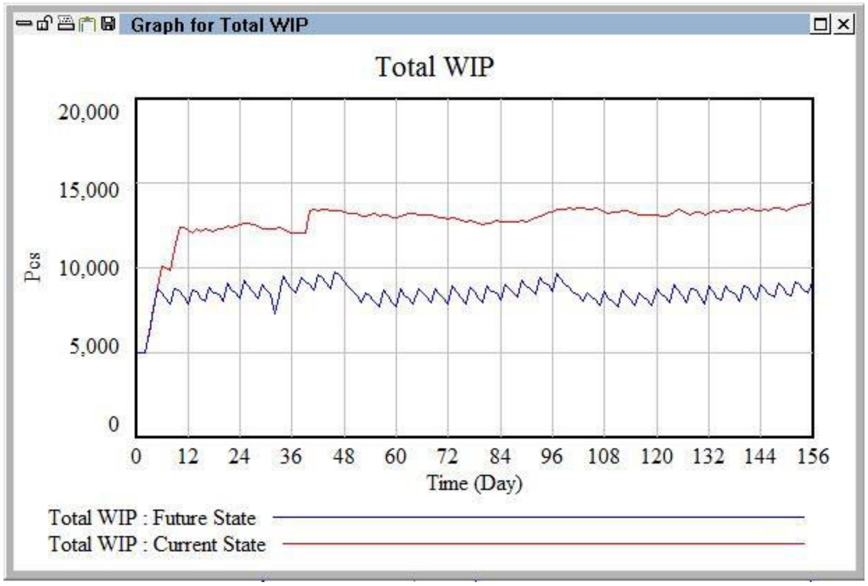

Figure 5: Total WIP in the current state and lean future state

As the figure shows, the WIP levels prior to lean implementation are continuously increasing over time, making it necessary for the manufacturer to continually acquire additional storage space, foregoing substantial investment money locked in inventory and being forced to regularly clear excess inventories at very low costs.

In the future state simulation, total WIP is reduced by 34% on average over the first 3 months starting immediately after the lean intervention. Furthermore, while the sudden disruptions at days 13 and 30 significantly impact system performance in the current state, these impacts are drastically dampened in the future state, as can be seen from the narrow range of fluctuations in the future state curve.

Actual improvement levels of the lean implementation in the factory were monitored over the first 3 months and a similar trend to the modeling results was observed in practice, with an average 8567 ± 902 pieces compared with the simulated average of 8,373 ± 862 pieces. This amounts to an actual net reduction in WIP of 31% on average over the first 3 months. And since the modeling results were sustained beyond 3 months as shown in Figure 5, no further monitoring was necessary on the factory floor, showing that system dynamics modeling can effectively serve to verify the long-term sustainment of the lean initiative in practice.

7. Conclusion and future work

This paper illustrated the use of system dynamics modeling to simulate the impacts of a lean manufacturing initiative at an apparel manufacturer facing several efficiency challenges. The initiative targeted the reduction of WIP in the factory and the main lean techniques used were Total Productive Maintenance, Kanban and Supermarket Pull. An SD model was built to represent the production operation and assess the impacts of the lean intervention before implementing it in practice. Modeling results showed a net reduction in WIP of 34% on average over the first 3 months, and the actual lean implementation showed a similar decreasing trend and a net average reduction of 31% in WIP over the same period.

The simulated improvement results were sustained for a simulation period of 6 months, and since the actual improvements in the factory showed a similar trend, only 3 months of monitoring were necessary on the factory floor to ensure the sustainment of the lean intervention. This shows the usefulness of system dynamics modeling for validating the long-term sustainment of lean implementations in practice.

In conclusion, the study showed that SD modeling can be useful in testing the potential benefits of a lean intervention prior to actual implementation, especially for ensuring that the achieved benefits are sustained over the long-term. This makes a case for investigating the potential sustainability of other lean techniques in similar as well as in different contexts in order to generalize the results of this study.

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Biographies

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