AN APPLICATION OF SIMULATION AND VALUE STREAM MAPPING IN LEAN MANUFACTURING

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ABSTRACT

Physical factory layout redesigns or changes of the supply chain infrastructure involve high costs. Through simulation and value stream mapping, managers can see the impacts before the implementation and transform the organization into a lean one at minimal cost. In this paper, we investigate some relevant lean manufacturing literature where lean principles and tools are presented or utilized. Two simulation models are built for two respective scenarios, push and pull (kanban) systems. Model templates are explained and the key measurements such as lead times, throughput rates, value-added ratios are compared as well as evaluated. The effects of lean are clearly demonstrated by the simulation.

I. INTRODUCTION

"Lean" has been originally created and defined as the elimination of *muda* (waste) in the book "The Machine that Changed the World" by Womack, Jones, and Roos (Womack et al. 1990). Several cases are illustrated in the sequel "Lean Thinking" (Womack and Jones 1996). In this book, crises in various business units with different cultures and mentalities (America, Germany, Japan), within several industries (manufacturing tools, cars, airplanes, ..., etc.), from a little company with 400 people to a big enterprise with 29,000 employees, are tackled by carrying out the key principles of lean philosophy (Womack and Jones 1996; Rother and Shook 1999):

(1) Define value from the perspective of the customer,
(2) Identify the value streams,
(3) Flow,
(4) Pull,
(5) Strive to perfection.

In the lean philosophy, "value" is determined by the end customer. It means identifying what the customer is willing to pay for, what creates "value" for him. The whole process of producing and delivering a product should be examined and optimized from the customer's point of view. So once "value" is defined, we can explore the value stream, being all activities – both value-added and non-value added – that are currently required to bring the product from raw material to end product to the customer. (Rother and Shook 1999). Next, wasteful steps have to be eliminated and flow can be introduced in the remaining value-added processes. The concept of flow is to make parts ideally one piece at a time from raw materials to finished goods and to move them one by one to the next workstation with no waiting time in between. Pull is the notion of producing at the rate of the demand of the customer. Perfection is achieved when people within the organization realize that the continuous improvement process of eliminating waste and reducing mistakes while offering what the customer actually wants becomes possible (Womack and Jones 1996; McDonald et al. 2000).

II. IMPLEMENTING LEAN CONCEPTS

Tools (methodologies) that are part of "Lean" are addressed in literature. In (McDonald et al. 2000; Rahn 2001), the pull technique of only producing what is required when it is required is used in the improved phases. The results are less rework and scrap, lower work-in-process, reduced lead time, increased throughput rate and higher service level. Other tools such as standard work (Cudney and Fargher 2001), quick changeover (Van Goubergen and Van Landeghem 2001; 2002), 5S (Henderson and Larco 2000), etc. can be referred to the works in the reference.

In contrast to the well-defined and rich set of lean tools and methods (Henderson and Larco 2000), as promoted by the Lean Enterprise Institute, there exist very few implementation methods. In recent years, *value stream mapping (VSM)* has emerged as the preferred way to implement lean. Value stream mapping is a mapping tool that is used to describe supply chain networks. It maps not only material flows but also information flows that signal and control the material flows. The material flow path of the product is traced back from the final operation in its

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routing to the storage location for raw material. This visual representation facilitates the process of lean implementation by helping to identify the value-added steps in a value stream, and eliminating the non-value added steps/waste (muda) (Rother and Shook 1999).

Despite its success, VSM has some drawbacks:

(1) VSM is a ″paper and pencil″ based technique used primarily to document value streams. It is composed by physically ″walking ″ along the flow and recording what happens on the floor. This will limit both the level of detail and the number of different versions that we can handle.
(2) In real world situations, many companies are of a high variety, low volume type, meaning that many value streams are composed of many tens or hundreds of industrial parts and products. This adds a level of complication (and variability) that cannot be addressed by normal methods.
(3) Revealing as a VSM map can be (see Figure 1 and 2 as examples), many people fail to ″see″ how it translates into reality. So, the value stream map risks ending up as a nice poster, without much further use.

III.SIMULATION AS PART OF VSM

To address these shortcomings while preserving the intuitive set of symbols of VSM, we propose to use simulation as a documentation and implementation tool. Two ways of simulation are shown in the papers:

(1) *Physical Simulations*
Whitman et al. present a physical simulation game where participants operate workstations along the assembly line in a mythical aircraft plant. Through a series of four scenarios (different supply chain maps), participants encounter supplier, service level, quality control problems and so on. As a result of participating this game, people implement and learn about lean concepts such as cellular manufacturing, pull system, one-piece-flow, etc (Whitman et al. 2001). We introduce here a physical game, building Styrofoam trains. It has been adopted for VSM use based on the JET game described in (Van Landeghem and Dams 1995).

(2) *Computer-Aided Simulations*
In (Van Landeghem and Debuf 1997; Van Landeghem 1998; McDonald et al. 2000; Rahn 2001), simulation models are built by using computer software and applied to the real world cases. Simulations are used to model manufacturing processes for a core product family and validate the current state map as well as evaluating alternative scenarios of future state maps.

We see two main reasons for using of simulation models:

(1) *Simulation as a Cost Saving Tool*
The use of a simulation model can help managers see the effects before a big implementation: the impact of layout changes, resource reallocation, etc. on the key performance indicators before and after lean transformation without huge investment (Van Landeghem and Debuf 1997, Rahn 2001).

(2) *Simulation as a Training Tool*
In most companies, especially when they are small, new concepts are hard to introduce. Simulation has proven to be a powerful eye-opener (Van Landeghem and Debuf 1997; Van Landeghem 1998; Whitman et al. 2001). By combining simulation with the visual map of VSM, we aim to achieve faster adoption and less resistance to change from the workforce.

IV.THE EXAMPLE

A mythical train manufacturer produces multiple products (general trains, fast speed trains, freight trains, etc.). We choose a core product family, general trains that exist in 3 different sizes – large, medium, and small. After drawing its value stream maps (current state and future state), we build the simulation models representing these two maps. This example exists as a physical simulation game (Van Landeghem and Dams 1995). By using the same example, we will compare in future experiments with simulation approaches.

There are two scenarios being simulated. The two supply chain networks that we simulate are shown in Figure 1 and 2. The first scenario or the "current state" is a MRP (Material Requirements Planning) based production system. There is a production control-planning centre, which generates the time schedule specifying the time (when) and the amount (how much) of materials, parts, and components that should be ordered or produced. The manufacturing processes (the rectangles in Figure 1) consist of material purchasing from suppliers, cutting strips, cutting A/B type strips, cabin assembly, chassis assembly, final assembly and shipping to customers. A typical characteristic of this kind of production system is the inventory storage points in between (the triangles in Figure 1).

The second scenario or the "future state" is a kanban based system (Figure 2), also called "lean production" system, which is based on the logic that nothing will be produced until it is needed. When a train is ordered by a customer, firstly, the last workstation takes the parts needed from the upstream supermarkets. The supermarket is a tool of the pull system that helps signal demand for the product. In a supermarket, a fixed amount of raw material, work in process, or finished product is kept as a buffer to schedule variability or an incapable process. A supermarket is typically located at the end of a production line (or the entrance of a U-shaped flow line) (Rother and Shook 1999).

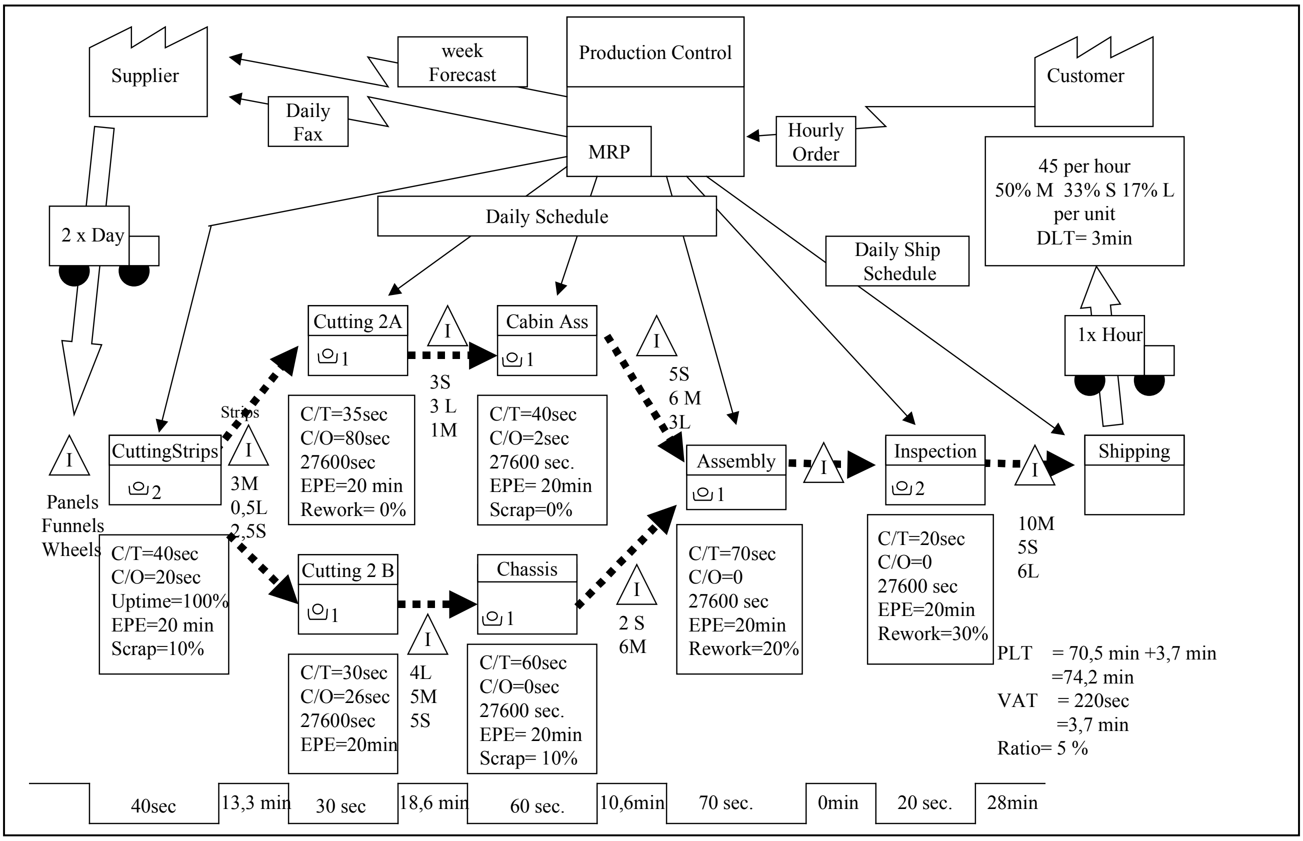

Figure 1: Scenario 1 (Current State) – A Push System

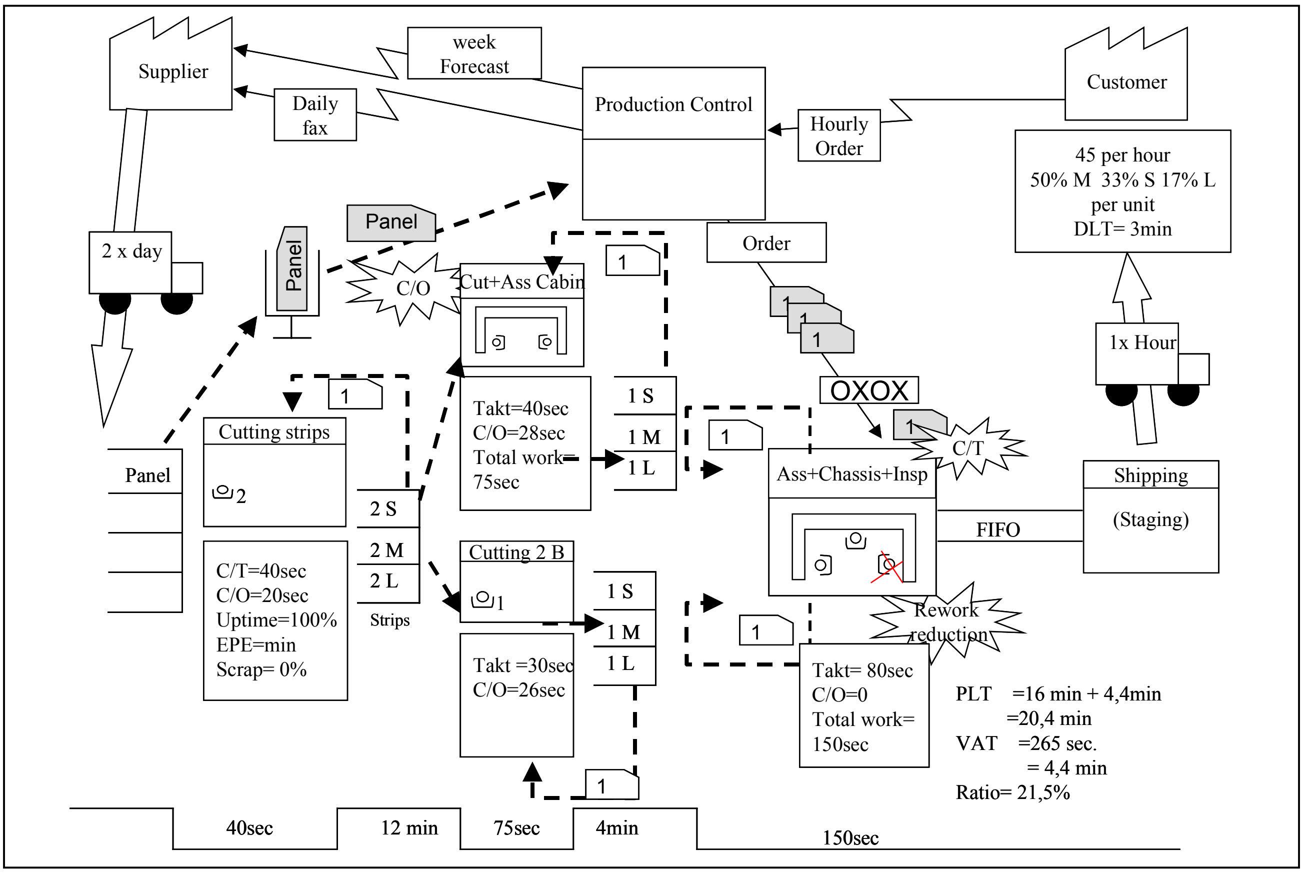

Figure 2: Scenario 2 (Future State) – A Pull (Kanban) System

Then, this last workstation starts fabricating the final product at the pace of "takt time" which is defined as the available production time divided by the rate of customer demand (Womack and Jones 1996; Rother and Shook 1999). When the parts are taken away from the supermarkets, this is the signal for the upstream workstations to produce new parts to supplement the parts taken away from the supermarkets. This upstream workstation then pulls from the next further upstream workstation, and so on all the way back to the original release of materials. Some features in the model are supermarkets, manufacturing cells (The layout of machines of different types performing different operations in a tight sequence, typically in a U-shape, to permit single-piece-flow and flexible deployment of human effort by means of multi-machine working (Rother and Shook 1999).), etc.

V. MODEL ELEMENTS AND KEY MEASUREMENTS USED IN THE SIMULATION

In this section, we explain some parts of our models in more detail and show their run modes (Figure 3 and 4).

1. Clustering Product Families

Using a VSM process requires development of maps. In the current state map, one would normally start by mapping a large-quantity and high-revenue *product family*. A product family is defined as "a group of products that pass through similar processing steps and over common equipment in your downstream processes" (Rother and Shook 1999; Khaswala and Irani 2001). The development of clustering algorithms for material flow aggregation will be explored further in our prospective research. In the simulation cases described in this paper, we simply model a product family comprising three products (large, medium and small train).

2. Simulation Templates

The templates of the simulation models are defined by using Arena ® from Systems Modeling Corp (Kelton et al. 1998). Table 1 lists the templates being developed for the second scenario.

Table 1: Basic Templates

Template	Contents
Customer	Start and end of the supply chain
Processing	Manufacturing steps in the supply chain
Supermarket	A interface/buffer between two processes ready to ship the parts or products when receiving a signal from downstream; a kanban would then be released to replenish the supermarket.
Flow Line	Processing flow of the products

•*The Customer Template*
A Customer is the start and the end of the supply chain. A customer order (demand) is the source of the flow and an order fulfillment is the end of the flow. As the supply chain network shows (Figure 1 & 2), the model starts with the order (an attribute about the train type is mentioned) from customers which is converted by a order processing function (a planning step) into final assembly, components fabricating or material purchasing authorization. The finished order is then packaged and shipped to the customers.

•*The Processing Template*
The processing template receives signals from customers or from downstream supermarkets to assemble, ship the final products or replenish the taken parts. Each processing template has a variable process time which is characterized by a triangle distribution function with minimum, mode, and maximum process time in seconds. In addition, a set-up time is considered in the processing machine between the fabrication of two different types of train according to the train type attribute which is mentioned in the customer order.

•*The Supermarket Template*
The supermarket template is a buffer (∃ in Figure 4) between two processing or flow line templates. It is ready to ship the parts or products when receiving a signal from downstream; a kanban would then be released to upstream to replenish the supermarket. As shown in Figure 4, the number in the signal card (kanban) represents the train type (1=large train, 2=medium train and 3= small train). When a cabin and a strip B of a specific train type are taken away from the supermarkets for the final assembly, there is a unique signal release from each individual supermarket to its upstream workstation respectively. These signals authorize the ″cutting A + cabin assembly″ workstation and the ″cutting B″ workstation to start producing and replenishing the taken cabin and strip B.

•*The Flow Line Template*
The flow line template is used in the special case of processing such as a manufacturing cell (a multi-stages, close-coupled flow line). For example, in the second scenario (Figure 4), every 80 seconds, there is a customer order arriving the company. Each order demands only one train (single-piece-flow) in the leveling ″232321″. The order processing center then gives a signal to the final assembly workstation (a manufacturing cell) which includes three process stages –assembling cabin and strips B, assembling chassis and inspecting the final products. This final assembly workstation is a flow line template that the parts or components needed (according to the train type) and taken from the upstream supermarkets (cabin and strip B supermarkets) all go through the same three-stages flow before they are shipped to the customer. The total processing takt time of this flow line template must be less than 80 seconds, which is the demand takt time.

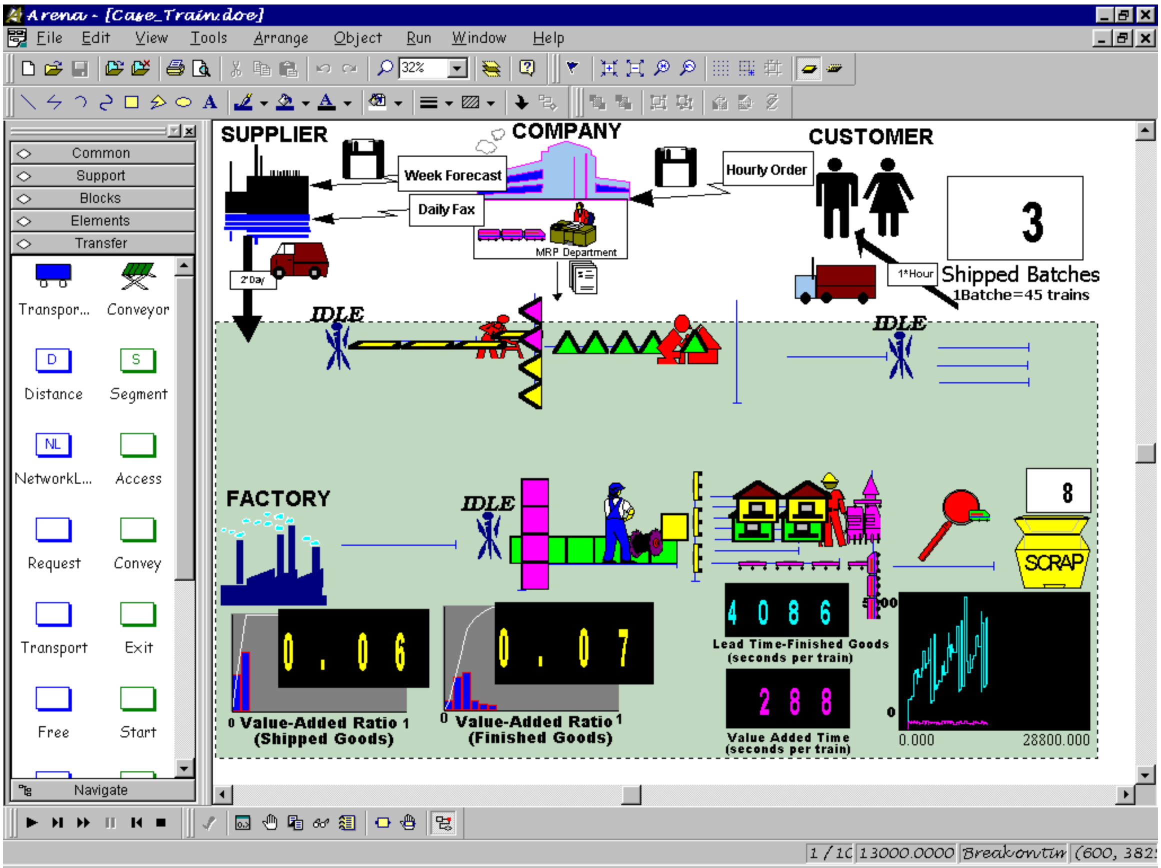

Figure 3: A Scene of Simulation Model in Scenario 1 (Push)

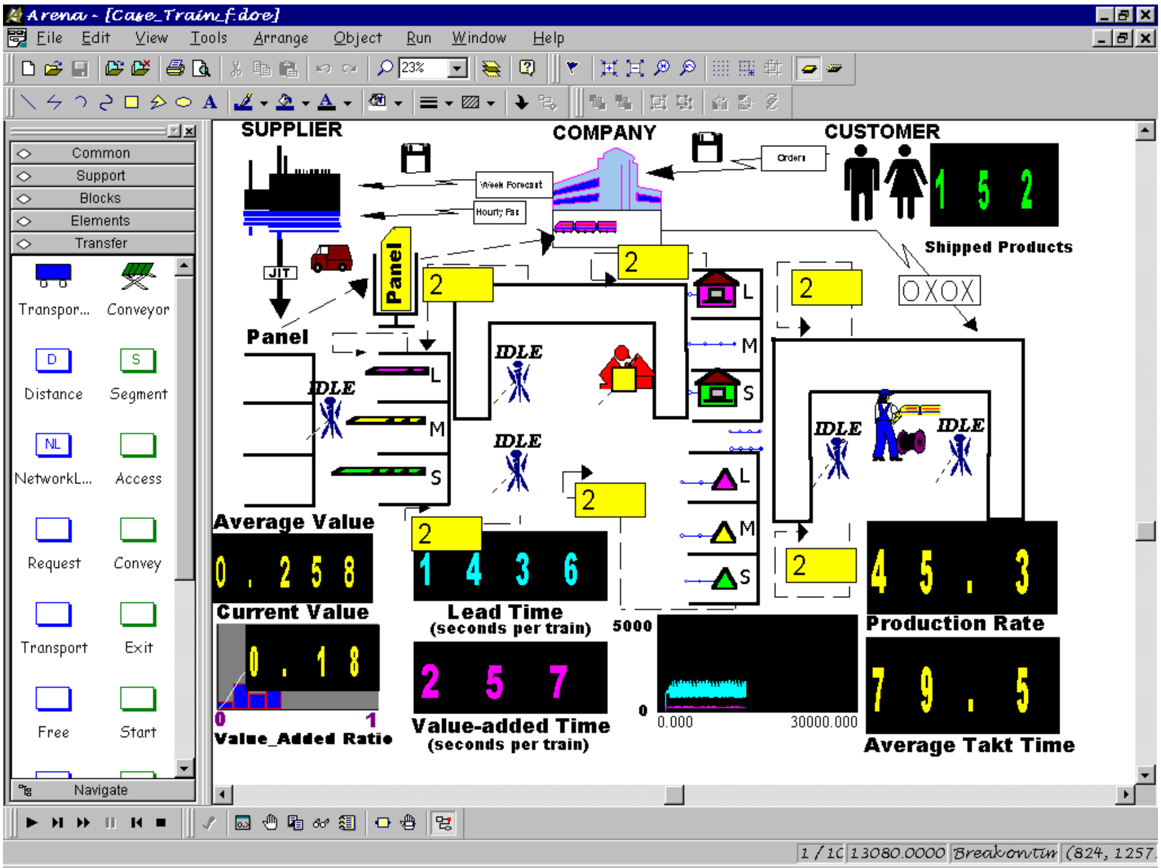

Figure 4: A Scene of Simulation Model in Scenario 2 (Pull)

3. Key Measurements

The definitions of our key measurements are given as follows (Hopp and Spearman 1996; Rother and Shook 1999):

•*Throughput (TH)*
The average output of a production process per unit time (e.g. parts per hour).

•*Work in Process (WIP)*
The inventory between the start and end points of a product routing.

•*Lead Time (LT)*
The total time a customer must wait to receive a product after placing an order. When a scheduling and production system are running at or below capacity, lead time and throughput time are the same. When demand exceeds the capacity of a system, there is additional waiting time before the start of scheduling and production, and lead time exceeds throughput time.

•*Utilization*
Fraction of time a workstation is not idle for lack of parts (If a workstation increases utilization without making other changes, average WIP and lead time will increase in a highly nonlinear fashion – bottleneck).

4. The Simulation Scenes

As the animation shown in Figure 3, which represents a push production system, we can see that there are batches and queues, scrap and rework, long lead times and low value-added ratios, etc. Compared to Figure 4, which represents a pull-kanban system, the batches and queues are replaced by supermarkets and single-piece-flow, there are no scrap and rework due to the flow line design, and the consequences are shorter lead times and higher value-added ratios.

VI. THE RESULTS

We take the average values from the output data of 10 replications and summarize them in Table 2. 8-hours is a replication run (a working day) and there is a 14 minutes warm-up time considered in the second scenario for preparing the fixed amount of raw material or work in process in each supermarket. We assume there is no waste time during any processing stage and define the value-added time as the sum of process time.

As we can see from Table 2, the lean production system (Scenario 2) improves the lead time by 78%, increases value-added ratio from 5.9 to 25.9, reduces WIP and relieves the bottleneck in the final assembly workstation.

We take the case of lead time as an example to explain the p-value in the table. The testing hypotheses are as follows:

$$\begin{cases} H_0 : \mu_1 \le \mu_2 \\ H_1 : \mu_1 > \mu_2 \end{cases} \Rightarrow \begin{cases} H_0 : \mu_1 - \mu_2 \le 0 \\ H_1 : \mu_1 - \mu_2 > 0 \end{cases}$$

Where,

μ_1: average lead time of push system
μ_2: average lead time of pull system

$$P - Value$$

$$= Prob\,(Z > \frac{X - Y - 0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}})$$

$$= Prob\,(Z > 30.46581) = 0 < \alpha$$

$\Rightarrow$ Reject H_0 that the average lead time of push system is less or equal to the average lead time of pull system.

Where,

X: sample average lead time of push system
Y: sample average lead time of pull system
s_1^2: the lead time variance of push system
s_2^2: the lead time variance of pull system
n_1: the sample number of push system
n_2: the sample number of pull system
α: the significant level (0.05)

The lead time (in hours) of 0.31 for pull system is likely less than the lead time of 1.39 for push system at a p-value equal to 0. It means that we reject the null hypothesis H_0 and accept the alternative hypothesis H_1 — the average lead time of pull system is less than that of push system and conclude that the pull approach has shorter lead times and is better than the push approach.

In the case of p-value equal to 1, it means that we do not reject the null hypothesis H_0 and the value of that key measurement in the push approach is less or equal to the value in the pull approach. For instance, the key measurement ″value-added ratio″ has p-value equal to 1, meaning that we don’t reject the null hypothesis that this ratio of push is smaller or equal to the ratio of pull.

Table 2: Simulation Output Data (10 Replications)

Key Measurements	Scenario 1 (PUSH)	Scenario 2 (PULL)	P-Value
Throughput (trains per hour)	45	45	--
Lead Time (hours)	1.39	0.31	0.0000
WIP (# of trains)	60	14	0.0000
Value-Added Ratio*	5.9	25.9	1.0000
Utilization (%)			
Cutting Strips Operator	51.0	74.9	1.0000
Cutting A Strips Operator	74.2	78.6	1.0000
Cutting B Strips Operator	53.0	69.6	1.0000
Cabin Assembly Operator	60.3	49.8	0.0000
Chassis Operator	87.9	74.8	0.0000
Assembly Operator	96.2**	87.3	0.0000
Inspection Operator	27.3	24.9	0.0000

*Average [Value-Added Time/Lead Time]
**High Utilization –Bottleneck

VII. A SIMULATION BASED VSM METHOD

Because value stream mapping (VSM) is a paper and pencil tool of lean manufacturing, there are two drawbacks: (1) VSM is time-consuming; (2) VSM doesn't detail the dynamic behavior of the production process and causes the barriers to effectively apply the improved situations. Therefore, we propose a modified use of VSM which includes four phases.

Phase 1: One Product – Static

This phase constructs a paper and pencil VSM of one product according to the classical method (Rother and Shook 1999). It ensures the insight and fact-finding that is crucial to introducing VSM in a real life situation. This will yield the current and future state map of one product.

Phase 2: One Product – Dynamic

In phase 2, we propose to build the simulation model based on the current and future state maps of phase 1. This should be fairly efficient when a model generator is used as we propose. This phase will yield a model whose results can be compared to the static situation, thus validating the model. This phase is of utmost importance to generate trust in the simulation model among users and process owners.

Phase 3: Multiple Products – Dynamic

In phase 3, we suggest the usages of simulation models to gauge the impact of VSM on multiple products. Additionally, different conditions and parameters can be investigated. Because of the switch to computer-based simulation, we can also use data mining techniques to obtain the data from multiple product streams. This preparatory step will need further research.

Phase 4: Multiple Products – Dynamic – A Training Tool

In the last phase, the simulation model can be used to document the future state conditions and as a training tool for the operators.

Phases 2 to 4 are new to the VSM implementation methodology. This paper contributes to the VSM use of phase 1 and 2.

VIII. CONCLUSIONS

In this paper, we have used a simulation tool to prove some effects of lean manufacturing. By changing the processing sequence, redesigning the layout and pulling the production from downstream (the customer), we reduce the lead times, lower the WIP inventory, increase value-added ratios and solve the bottleneck problem. We proposed an extended VSM implementation method based on simulation.

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