A SIMULATION FRAMEWORK TO HELP IN LEAN MANUFACTURING INITIATIVES

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ABSTRACT

Lean Manufacturing initiatives try to understand where the sources of waste are in a manufacturing process in order to minimize or avoid them and to add value to the stakeholders. The improvement actions related to lean methods are always incremental, fast and easy; mainly based on people's experience and on simple tools. For example, a Value Stream Map (VSM) is created to have a visual representation of the material and information ¤ows involved in the production process, allowing improvement teams to detect where is the waste introduced and where is the value added.

The integration of simulation with VSM could considerably improve the results obtained in lean projects, helping the decision makers in adding dynamic information to the usually considered static pictures of the processes. The information obtained from what-if simulations allows to detect improvement opportunities, to prioritize them, to analyze the best implementation alternative, and to quantify the possible bene£ts of the proposed actions.

This work presents the LeanSim framework, an easy to use tool based on Matlab and Simulink, capable of integrating a lean method such as VSM with simulation. Furthermore, a case study of an improvement project at a milk production plant is presented to illustrate the utilization of this new framework on a real environment.

INTRODUCTION

The key concepts in the current competitive and globalized context are reducing costs while increasing quality. Furthermore, only ¤exible organizations with fastest adaptation time acquire a competitive advantage and survive in today's demanding markets.

This changing scenario leads to new manufacturing paradigms capable of providing ef£ciency, responsiveness and quality such as Lean Manufacturing (Shah and Ward, 2007).

The lean paradigm involves dynamic, continuous and customer-focused improvement processes designed to eliminate waste and to create value to the organization stakeholders (enterprise, workers, society and customers). All these processes are based on a group of more than a hundred methods and tools (Alukah and Gill, 2008), all incremental and knowledge-based, trying to take advantage of the ideas, experience and skills of everyone in the organization. And some have been speci£cally developed to Lean Manufacturing, while others are general methods which can be used in this kind of environment too.

In general, all these tools promote, in some way, a whole re-thinking of how to produce to eliminate waste. But almost all of them are based on "pencil and paper", because one of the challenges of the lean paradigm is to use only simple, fast and easy tools (Field, 2001). And the determination and prioritization of the improvement opportunities is based exclusively on the experience of the people composing the improvement team and on a set of well-known and easy KPIs (Key Performance Indicators).

This kind of declaration of principles has traditionally excluded simulation of the group of tools considered in lean initiatives. It is usually thought that simulation demands a large investment of time and resources and that expert knowledge of simulation methods and tools is needed. Although some recent works have pointed out the important advantages of using simulation to improve the results of lean projects (Lian and Van Landeghem, 2002; Evans and Alexander, 2007; Deif, 2010; Hoe et al., 2010), it is not a widely used practice yet.

The main contribution of this paper is to propose a £rst prototype for a simulation framework based on Matlab and Simulink, LeanSim, to support lean initiatives, speci£cally, those based on Value Stream Map (VSM) methods, although the proposed framework could be easily extended in the future to work supporting another lean methods and tools. The proposed framework has demonstrated to be very useful in experimenting with all the possible manufacturing system changes to £nd the best improvement options

before their implementation (a what-if simulation can help in understanding if a specific modification really implies an improvement) and in prioritizing their implementation.

The rest of this paper is organized as follows. Section 2 introduces the basic concepts of Value Stream Map methods and discusses previous works focused on improving their performance using some kind of simulation. Section 3 explains in depth the LeanSim, the simulation framework proposed to support VSM initiatives and discusses all the details related to its design and utilization. Section 4 presents a real case study to exemplify the use of the proposed framework and to verify its utility in lean initiatives. And finally Section 5 summarizes the most important conclusions and lines for future research.

BACKGROUND

Value Stream Map (VSM) is a lean method used to improve the flow of materials and information necessary to produce a product or a service, eliminating the waste and adding value (Rother and Shook, 1999).

This tool is based on drawing the current VSM diagram showing these flows, and the activities or processes involved in the production as well as the KPIs selected to measure their performance, typically, the Cycle Time (CT), the Change Over Time (C/O) and the Uptime for each activity or process. For the whole process, from end to end, the Total Lead Time and the Value Added Time are usually taken into account too. The materials flow is generally drawn from left to right, while information flow generally goes right to left. It is important to remark that the symbols used to create this kind of diagrams are standardized and they are easily drawn and recognized.

After creating the initial diagram, the involved improvement team, in which each area or stakeholder of the process must be represented, critique the current situation and the desired situation is formulated drawing the future VSM diagram. This new diagram is only a tool for graphically representing changes that could be made, therefore, to identity all the possible improvement activities usually called formal kaizen events.

The comparison between the current VSM diagram and the future VSM diagram helps the improvement team to prioritize these kaizen events and to propose an action plan to reach the desired situation for the process. Obviously, there are always many different options and alternatives to reach this state and the team should carefully consider all the involved variables and criteria (cost in time and resources, possible benefits, risks, etc) to choose the best method to perform the transition from the current state to the desired state.

Some recent works have proven that simulation could be a powerful tool to select the best alternative for moving toward the desired future state, for example (Solding and Gullander, 2009) or (Paju et al., 2010), because VSM itself does not improve anything. It is only an analysis tool, the action plan proposed by the improvement team is the actual improvement tool and a what-if simulation could significantly enhance this action plan. And there are some software solutions that integrate VSM methods and simulation, such as Process Simulator as a Microsoft Visio plug-in (ProModel, 2011) or Simcad and its Value Stream Analyzer (Createsoft, 2011), but all of them with limited functionalities.

Simulation is one of the most valuable tools for process improvement, and its value typically increases as the process to be improved becomes more complex and the decisions of the improvement team are more complicated. But to the moment, simulation is perceived as a too difficult and slow tool to be used in lean projects, and unfortunately, the first attempts to combine both types of methods are still simple and unmature.

PROPOSED FRAMEWORK: LEANSIM

In this section the LeanSim simulation framework, based on Matlab and Simulink, is presented. The main goal of this framework is to provide lean improvement teams with a simple, fast and easy tool capable of guiding them in their decisions. In this first prototype, the simulation framework is focused on supporting the VSM method, but the framework architecture has been developed to be easily scaled in order to support another lean tools related to the manufacturing flow such as Kanban, Takt time calculations or design of cell layouts.

Challenges

The goal of this work is to propose a framework that allows users to quickly create VSM diagrams and to provide them the capability of simulating ceratin parts of these diagrams to identify inefficiencies and to determine the best correction actions in lean initiatives. A number of challenges need to be addressed to reach this kind of simulation framework, the most important:

- Capability of rapidly and easily creating modular and scalable models parametrized to a specific process at a specific plant at a certain moment, if possible, reutilizing previous and/or pre-built models.

- If the models need to be built from scratch, the modeling process should not be a time-consuming process and no high expertise in simulation techniques should be required.

- The simulations need to be completely data driven and the data needs to be available from different kinds of inputs and in different standard formats. The static picture of the process, drawn with pencil and paper in traditional lean methods, must be easily completed with dynamic information.

- Capability of integration with other models, frameworks and applications.

The challenges mentioned above lead us to the selection of Matlab and Simulink (Mathworks, 2011) as the basis for the LeanSim framework. In fact, the proposed simulation environment is composed of a set of Matlab functions and a customized Simulink library (called *leansimlib*).

The main advantage of using Simulink is in its graphical user interface (GUI) for building models as block diagrams. Furthermore, models can be created using different approaches: assembling the model directly in Simulink using the standard available blocks or creating customized blocks, using Matlab M-files, programming S-functions or interfacing Simulink with other simulation tools and applications.

The graphical philosophy based on "drag and drop" makes it easy to get started building hierarchical models without deep knowledge about simulation techniques, and preliminary results can be rapidly obtained. But, at the same time, Simulink offers powerful tools to model complex systems allowing a tight integration with the Matlab environment and all its capabilities (for example to define model inputs the OPC toolbox may be used, the simulation outputs can be managed for analysis and visualization, the HLA/DIS toolbox can be used to build distributed simulations, etc).

Preliminary Definitions and Concepts

For many years, simulation has been used to analyze production and logistics problems. In many cases, Commercial-off-the-shelf Simulation Packages (CSP) support the development and visualization of simulation models in this kind of contexts.

The standard SISO-STD-006-2007 2.0 defines a set of Interoperability Reference Models (IRM) to create a common framework and to allow users to create distributed simulations for manufacturing applications consisting of CSPs and their models easily (Simon et al., 2007).

The simulation framework proposed in this work has been designed to be compatible with this standard in order to use distributed simulation in the future if it is needed to run complex projects based on distributed models. Therefore, the same terms and definitions have been used:

- **Model (M).** A model describes and represents a real world system.

- **Time (T).** It represents a specific simulation time in a model. Time is an integer value and in this standard does not have specific units to measure it.

- **Event (E).** An event specifes an instantaneous system transition between two different states at a time T.

- **Entity (e).** An entity is something that is processed, for example, a raw material or a product. It goes through some queues and activities representing the manufacturing system and it is defined by its attributes.

- **Queue (Q).** It is a queue of entities managed with some specific queuing discipline (LIFO, FIFO, etc), and the typical example is a plant buffer storing the inventory between two processes.

- **Activity (A).** It is a time consuming action, process or step with a known duration. The activity starts and ends with an event.

- **Resource (R).** A resource is something that is needed by an activity to begin. In manufacturing environments, typically the machines and operators.

- **Data Structure (D).** It is similar to a resource but there are modeling differences in terms of semantics. For example, it can be an inventory record, a production order or a bill of materials.

Therefore, in a traditional VSM diagram the material flows represent entities movements, the inventories are queues, the processes are activities, the machines and operators are resources and the information (automatic or manual) and kanbans are data structures.

LeanSim Architecture

As it has been said before, the this first prototype of the LeanSim framework is focused only in supporting VSM projects. Therefore, a Simulink library has been created (*leansimlib.mdl*) with three categories of blocks (figure 1). Initially, only a limited number of blocks has been defined inside each category but new blocks can be added in the future:

- **Activities.** Three blocks have been included in this category, a static activity, an input-from-Matlab activity and a dynamic activity. The traditional VSM data boxes used to show the processes KPIa are not needed in the LeanSim framework to give this information, because each activity is defined by its attributes through the Simulink parameters for each block.

- **Drawings.** The typical symbols used to create a VSM diagram have been included in this block category, initially: automatic information flow, customer, kaizen event, manual information flow, other (empty box for miscellaneous information), production control, pull raw (for materials flow), push raw (for materials flow), time line and truck.

- **Queues.** Two blocks have been included in this category, a FIFO queue and a LIFO queue.

LeanSim can be used to draw traditional VSM diagrams with Simulink without using simulation, as any other simple drawing tool. But if the improvement team decides to use simulation to guide the VSM method, the activities and queues are the blocks that can be simulated.
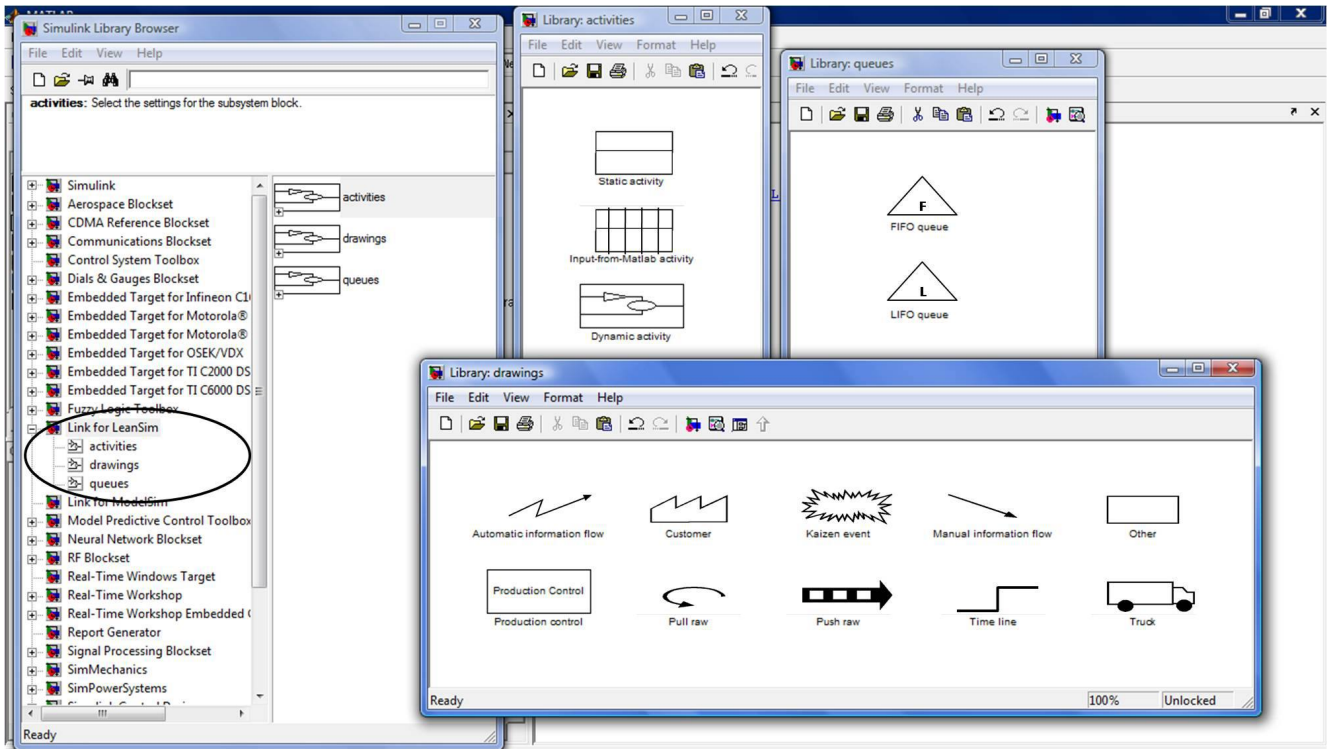
Figure 1: LeanSim Library and Sublibraries

In these cases, it has to be considered that a traditional VSM diagram rarely summarizes all the information needed to run an accurate and complete simulation. The LeanSim framework expands the information typically included in a VSM diagram so that it contains all the information needed to run a simulation. For example, each activity is defined by its CT, C/O and Uptime, but also by its associated resources (machines and operators) including information about possible sharing, and by the number of entities that the activity can process simultaneously. Therefore, the activities and queues blocks are configurable, with a right click on one of these blocks, the configuration window can be opened to define the block parameters (one example is shown in figure 2).

Some drawing symbols without simulation capabilities include configuration parameters through this kind of window too, because they can help in completing the VSM diagram information. For example, the time line include two parameters, the Total Lead Time and the Value Added Time and the information flows (automatic and manual) include a Frequency parameter (by shift, daily, weekly, etc).

Queue blocks. A queue block is designed to store entities. It has an input port and an output port, it tries to output an entity but if the output port is blocked, it keeps storing it. When the output port is open, the entities leave the queue. The difference between the two initially defined queues, FIFO queue and LIFO queue are only in the queue

management policy, FIFO (First In First Out) or LIFO (Last In First Out).

The configuration window in this category is very simple because only two attributes are defined. The first, the Queue length. A queue block is able to store up to L entities at the same time, if the queue stores exactly this number of entities, the queue is full and cannot accept new entities until new space is available. An the second, the Average WIP (Work in Progress) in hours, to quantify the mean delay of entities inside the queue.

Activity blocks. For the blocks in this category, the configuration window is divided in three areas: the performance attributes area, the resource attributes area and the capacity area (figure 2).

The performance attributes are the CT, the C/O and the Uptime (all in seconds), while de resource attributes are the Number of machines, Availability of machines (as a percentage), Number of operators and Availability of operators (again as a percentage). Finally, the capacity attribute is only one, the Number of entities which can be processed at the same time by this activity.

The differences between the three initially defined activity blocks are mainly in the method used to give values to the performance attributes and in their simulation capabilities:

- **Static activity:** All the performance attributes values

Table 1: De£nition of the Considered Line (L105) Activities Attributes

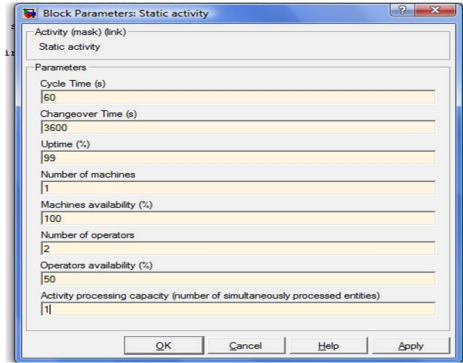| Activity	CT (s)	C/O (s)	Uptime (%)	Machines	Machines av. (%)	Operators	Operators av.(%)	Number of entities
Liquid £lling	0.18	600	57	1	100	4	100	1
Sealing/caping/labeling	0.2	60	99	2	100	2	100	1
Baling	0.15	300	99	1	100	2	100	4
Packing	0.14	3600	98	6	100	3	100	40

Figure 2: Example of Block Con£guration Window: Static Activity Block Attributes

Table 2: De£nition of the Considered Line (L105) Queues Attributes

Queue	Management	Queue Length	Average WIP (h)
Bales inventory	FIFO	192.000	24
Pallets inventory	FIFO	300.000	24

are statically £xed by the user in the same way that the resource attributes. In fact, this kind of activity is a drawing symbol and corresponds to the traditional process symbol in a VSM diagram, without simulation capabilities.

- **Input-from-Matlab activity:** The performance attributes are linked to variables de£ned in the Matlab environment and they are completely dynamic. Therefore, they can be the result of some computation, or they can be obtained from an external information source such as an Excel datasheet or an OPC server.

- **Dynamic activity:** In this case, the activity is actually a Simulink subsystem. The block is only a high level abstraction, but with a double-click increasing levels of detail can be simulated to obtain the performance parameters for the considered activity and to perform what-if simulations.

CASE STUDY

In this section, the LeanSim framework is used to identify and to prioritize the formal kaizen events present in the £nal part of an enriched liquid milk manufacturing process.

Speci£cally, the VSM method has been used at a milk production plant in order to improve the £lling/packing line (coded L105) for the one liter plastic bottle format, because this line has been the bottleneck of the whole manufacturing process during the last year.

A lean multi-functional team is created with 8 people (utility specialists, process specialists, product specialists, quality manager and production manager, this last as the team leader) during 3 months to develop this VSM project. They £rst de£ne the project scope and objectives and collect all the needed process information. Tables 1 and 2 summarize the features of the line to improve and £gure 3 shows the initial VSM diagram built with the LeanSim framework. It has been simpli£ed only to show the considered line in order to ease the understanding of this case study and it only shows the essential information related to the main activities (the information ¤ows and other details are not included in this version). It can be seen that four activities are taken into account by the lean improvement team: the liquid £lling, the sealing/capping/labeling, the baling (in bales of 4 bottles) and the packing (in pallets of 10 bales).

Initially, the VSM diagram has been created as a traditional draw, without simulation capabilities. Once the kaizen events have been identi£ed (in this speci£c case, three of these events are going to be explored), some parts of the diagram have been transformed to take advantage of the what-if simulation capabilities of the proposed framework. The three kaizen events are related to the liquid £lling activity uptime, to the sealing/caping/labeling activity wastes and to the packing activity (and associated inventories) bottleneck. Therefore, two Input-from-Matlab activity blocks have been used to model and simulate the liquid £lling and sealing/capping/labeling activities, and a Dynamic activity block has been selected for the packing activity. With this transformation the simulation results can be used to de£ne and to prioritize all the possible improvement actions shown in the £gure as kaizen events. The two activities modeled with Input-from-Matlab activity blocks use data from an external Excel datasheet to accurately analyze all the possible improvement actions. The packing activity has been modeled in detail with a SimEvents model because the whole packing process needs to be redesigned.

All these speci£c models are out of the scope of this paper, but the important conclusion is that a future VSM diagram has been created with the help of these simulations and concrete actions to perform the transition from the current state to the desired state have been de£ned:
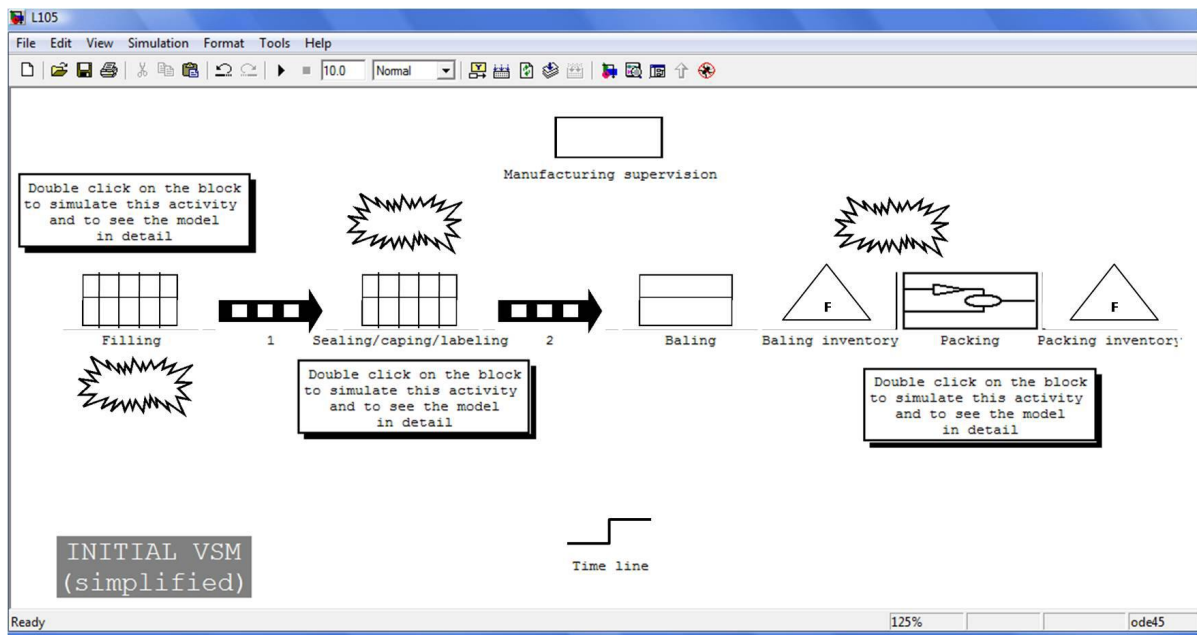
Figure 3: Simplified Initial VSM Diagram for Manufacturing Line L105

1. Redesign the packing activity and its inventories to reduce the WIP average time of the bale inventory from 24 hours to 8 hours. This improvement decreases the Total Lead Time from an initial value of 2 days (48 hours) to 32 hours.

2. Increase liquid filling machine uptime from 57% to 70% solving the most important unsterility causes. This can be done by involving the filling machine manufacturer in some updating and maintenance tasks, implementing TQM and installing new visual controls at the plant.

3. Implement a new cell for the sealing/caping/labeling activity to smooth the line, establishing cleaner and more organized work areas (with the 5S method) and avoiding unnecessary material and operator movements.

CONCLUSIONS AND FUTURE WORK

Simulation has been used in the past for training and education in the context of Lean Manufacturing, but it is not usually considered as a lean tool.

In this work a simulation framework based on Matlab and Simulink, LeanSim, has been presented. The first goal of this framework is to demonstrate that simulation can bring important benefits to lean initiatives allowing the identification, definition, evaluation and prioritization of the improvement actions.

The first version of the LeanSim framework has been designed to support Value Stream Map projects. A VSM diagram presents only a static view of the process and fails in capturing the dynamic interactions between all the involved agents. Simulation adds the fourth dimension to VSM, time, transforming a static snapshot on a much more complete and powerful what-if analysis tool. It allows the lean team, not only to determine which improvements can move the system towards the desired state, furthermore, to quantify the amount of improvement that can be expected.

All these advantages have been illustrated with a real case based on a VSM project in an enriched milk manufacturing process. The LeanSim framework has demonstrated to be a useful decision-making tool in fast improvement events, avoiding exclusively human-dependent decisions based only on qualitative methods and past experiences.

We are currently working in many interesting lines related to this work. The LeanSim library is being completed with new blocks, templates and functionalities in order to improve its usability in VSM projects and to support another lean methods. And when the library is finished, our intention is to create a website where it can be freely available for download and for receiving feedback from users. Finally, we are developing a methodology to model manufacturing processes on multiple levels of detail using hierarchical modeling with the LeanSim framework.

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