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WHY LEAN NEEDS SIMULATION

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ABSTRACT

Lean methods have become the standard approach to the resolution of design and operational issues in production and other systems. However, the lean approach has deficiencies. The deficiencies that simulation can address are presented, discussed and illustrated. These deficiencies include modeling and assessing the effects of variation, making use of all available data, validating the effects of proposed changes before implementation as well identifying other possible improvements, and assessing the interaction effects between system components. Various industrial applications are presented that show that simulation was required to successfully address operational issues that the lean approach failed to identify and could not resolve.

1 INTRODUCTION

Lean principles are commonly used in the design and operation of production systems. Lean manufacturing has been defined as: "A systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection" (NIST/MEP 1998). Alternatively, Spearman (2003) described lean as the efforts to minimize the kind of buffers usually found in a manufacturing system: excess capacity, excess lead time, and inventory. Tapping, Luyster, and Shuker (2003) give an overview of the lean approach.

Identifying and specifying the role of simulation within the lean approach seems valuable and even necessary in expanding the simulation application base (Diamond, et. al 2002). Adams, et al. (1999) give an overview of how simulation could be used within the lean manufacturing strategy.

1. In identifying problems in manufacturing or other processes.
2. For training operations personnel in the way the process operates.
3. For ranking the various opportunities for process improvement.
4. For documenting the process.
5. For predicting the impact of accepted improvements before implementation.

Ferrin, Muller, and Muthler (2005) describe the benefits of using simulation as part of a lean – 6σ combined process. Simulation provides a more powerful tool (a 6σ capable tool) than those commonly used in a lean – 6σ process. Simulation is uniquely able to support achieving a corporate goal of finding a correct, or at least a very good, solution that meets system design and operation requirements before implementation.

The compelling reasons that simulation should be used to extend the lean process, including the one given by Ferrin, Muller, and Muthler, are identified, described, and illustrated in the next section. These compelling reasons are based on deficiencies in the lean process. Industry-based case examples are given to show the necessity of using simulation in addition to lean techniques.

2 LEAN DEFICIENCIES AND SIMULATION CAPABILITIES

The compelling reasons for using simulation to enhance the lean process have been identified based on numerous experiences performing simulation studies in industrial environments.

1. Variation must be addressed, both random and structural.
2. Data must be fully analyzed to help understand the random nature of system behavior.
3. The interaction between system components must be assessed.

4. The future state must be validated before it is implemented to minimize or eliminate the period of trial and error adjustments.
5. Alternatives to the future state must be systematically identified and considered.

Each of these will be discussed and short examples given.

2.1 Variation Must Be Addressed

Lean is inherently a deterministic method. Yet important operating parameters and characteristics of many manufacturing systems are random variables, for example customer demand, the time between part arrival for processing, shipping times, machine breakdown and repair intervals, and operation times.

Furthermore, a manufacturing system may have structural variation or variation designed into the way it operates (Hopp and Spearman 2000). For example, suppose a customer demands delivery of a particular product five days per week but the product is only produced on Monday, Wednesday, and Friday. Thus, by design the system behaves differently on Monday, Wednesday, and Friday than on Tuesday and Thursday.

Random and structural variation impact capacity, lead time, and inventory requirements. Without variation, no inventory would be required. While lean methods acknowledge the need for inventory due to variation in customer demands and production behavior, no methods are provided for computing how much is needed. The rule of thumb: use two days inventory is suggested. However, no method of validating whether this is too little or two much inventory is provided.

Lean methods suggest removing as much variation as possible over time and then adjusting inventory levels based on experience. Changes in customer demand or production system capabilities would require this entire trial and error process to be repeated.

Maas and Standridge (2005) describe the use of simulation in a lean manufacturing context. Random variation due to customer demands and machine breakdowns as well as structural variation due to multiple part types with different production schedules are taken into account. The simulation analysis showed that customer services levels could be met given specified production schedules and analytically computed inventory sizes.

As an example of structural variation seen in this study, consider the production schedule for the 21 part types produced by this production system. Eleven part types are produced on Monday and Tuesday. Nine are only produced on Monday and another nine only on Tuesday. Two are produced on both days. Only six part types are produced on Fridays. Thus, most part types are produced two or three days per week, one is produced everyday, and one is produced only on Friday.

2.2 Data Analysis

Since lean procedures are inherently deterministic, data is obtained only for the purpose of computing the average of quantities such as customer demand, down times, and operation times. A more thorough analysis of the data would include an examination of the variability, a determination as to whether the data was homogeneous, and an estimation of a probability distribution that fits the data, including the distribution parameters. Homogeneity, for example, has to do with determining whether the demand on Monday follows the same probability distribution as the demand on Tuesday.

The simulation study performed by Maas and Standridge included a thorough examination of shipment data which was used as a surrogate for customer demand. The shipment data was specified in parts. Dividing by the pallet size showed that the number of pallets shipped per day followed a discrete probability distribution. Thus, random variation in customer demand could be included in the simulation model.

For example, the demand for one particular product was between zero and nine pallets per day and followed the distribution shown in Table 1.

Table 1: Discrete Distribution of Demand

Pallets	Probability
0	0.52
1	0.03
2	0.07
3	0.06
4	0.08
5	0.04
6	0.09
7	0.02
8	0.04
9	0.03

2.3 Component Interaction

Lean procedures tend to focus on each component of a manufacturing system individually without determining the interaction between components. Some of these component interactions are discussed by Hopp and Spearman (2000). Their importance in a simulation study is discussed by Standridge (2004).

For example, consider a pull system with highly variable customer demand. Reducing the variation could reduce the amount of finished goods inventory needed. In addition, the time to produce a replacement item could be reduced sufficiently to allow a reduction in capacity or in production lead time targets.

Lean methods would use trial and error over time to access the effectiveness of such reductions. Simulation could be used to quantify and validate inventory and capacity reductions before they were made.

2.4 Validating the Future State

Value stream mapping is a fundamental lean activity. A map shows the flow of one product through its operations and includes parameters such as operations times and inventory levels as well as control structures, deliveries to customers, and arrivals of raw materials. The current state map shows the current conditions in a system. The future state map shows an ideal state for the system that can pursued over time.

The definition of the ideal state is developed through a group process performed by the lean team. Since a value stream map is a descriptive model, there is no mechanism for analyzing it to see if the specifications it contains will produce the desired system behavior or achieve performance targets. Furthermore, the value stream map does not include variability information.

Some software exists for translating a value stream map into a simulation model. Since the variability information is not included, the utility and perhaps even the validity of such models may be in question.

Grimard, Marvel, and Standridge (2005) describe the validation of a future state of a re-designed injector calibration work cell using a deterministic simulation. Simulation results were used to refine initial estimates of throughput and validate worker movement in the cell. The latter is illustrated in Table 2.

Table 2: Calibration Area Worker Task Pattern

Simulation Time (min)	Station	Task	Part ID
1785.51	VOP	Removal	81
1785.69	VOP	Operation	82
1786.19	VOP	Walk to Nutstack	81
1786.23	NUTSTACK	Operation	81
1790.19	NUTSTACK	Walking to Calibrator	81
1790.25	CALIBRATOR	Removal	58
1790.25	CALIBRATOR	Operation	59
1790.34	CALIBRATOR	Walk to Pin Mark	58
1790.38	PINMARK	Operation	58
1790.46	PINMARK	Walking to Pack	58
1790.50	PACK	Operation	58
1790.58	VOP	Removal	82

Worker movement from station to station along with the number of parts moved is shown. Movement is accomplished in the desired pattern and only four parts are handled in keeping with the principal of one piece flow. The worker is shown to be the bottleneck since the 5.07 minutes are required to complete one movement among the stations.

2.5 Future State Alternatives

The future state map is developed using a group process. Thus, it is not possible to know if the group found the best future state with respect to desired levels of system performance or examined all, at least most all, possible future states in a systematic way.

Such an examination of a solution space can be done with a carefully designed simulation experiment. In addition, optimum seeking methods can be used to search for the combination of experiment parameters values that produce at least a very good result with respect to performance measure values of interest. Furthermore, "what if we did this" cases can be evaluated.

Grimard, Marvel, and Standridge (2005) describe a simulation experiment in which work cell throughput is estimated as a function of allowed work-in-process inventory levels using a designed simulation experiment. The results are shown in Figure 1. Throughput increases up to an asymptote as the number of WIP racks is increased.

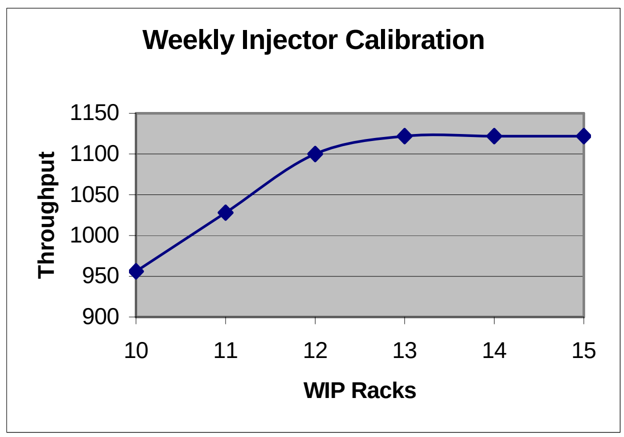

Figure 1: Throughput Versus WIP Racks

In addition, a what if scenario examined the effects on work cell throughput when staffing the cell with two workers compared to the case where only a single worker was used. The second worker was assigned to the bottleneck station while the first worker moved between the other stations. The simulation experiment showed that the throughput increased slightly. Parts still waited while the first worker was busy at another station.

3 INDUSTRY CASE EXAMPLES

Several industry case examples are used to illustrate in more detail how simulation addresses the deficiencies in the lean process. Note that in each example multiple deficiencies are identified.

3.1 Case Example #1: Fabricated Metal Wire Products

Marvel, Schaub, and Weckman (2005) illustrated how the lean transformation process was unable to address issues of interaction of system components and required a simulation to validate the future state. A thorough analysis of data concerning a critical system operating component was required to examine the variation as well as to fit a distribution function. Based on the simulation, alternatives to the future state map were identified. One of these was selected for implementation.

The manufacturer of stamped and fabricated metal wire products was experiencing production related problems that impacted the ability to meet customer demand and to operate the facility in an efficient manner. The production system was based on the manufacture of products in large lot sizes due to equipment requirements and customer demands. The facility was arranged in a series of product flow lanes. An individual product would be assigned to a primary flow lane where it would undergo all necessary processing operations. During the production process the finished good would be wound onto large diameter spools. The spools of finished goods would then be shipped to a tier one supplier. The supplier would then assemble these goods with other components to form a subassembly that is shipped to the original equipment manufacturer.

The lean initiative focused on developing a production system that could efficiently produce the products that were critical to the success of the business. These products were identified through statistical analysis of historical production data. The analysis resulted in identifying approximately twenty products out of the manufacturer's complete product line of over seventy products as the critical products. The philosophy for the design of the production system was to assign these critical products to a specific flow lane for production based on a repetitive cycle. After assigning the critical products to their associated flow lanes, each flow lane contained excess capacity that was used for the production of the non-critical products. The non-critical products would then be produced using these "open" capacity gaps on the different flow lines.

A fundamental component in the production system design was the availability of spools in the system. Spools were supplied by the customer and the number of spools supplied to the manufacturer were negotiated at the beginning of a product launch. As product was manufactured and wound onto these spools, the spools were shipped to over twenty unique customers. These customers used the product in their manufacturing process, removing the product from the spools, and the empty spools were shipped back to the manufacturer. The spools used in these processes were not generic but customer specific and as such product had to be placed on specific spools. The production system acted as a closed queuing network in which there are a fixed number of spools in the system. The spool flow in the simulation system is shown in Figure 2.

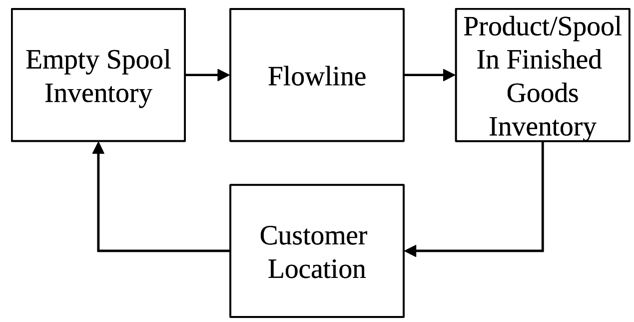

Figure 2: Spool Flow

The lean planning process, driven by a gross capacity analysis, was unable to address the following questions:

1. Were there enough spools in the system to meet the market demand requirements taking into account logistical considerations?
2. Was there enough open capacity slots to meet the demand for the non-critical products?

The objective for developing a simulation model was not only to project the number of customer specific spools that were necessary for the system to operate efficiently for all the products but also to determine if enough "open" capacity gaps were available at the correct time in the correct flow lanes to meet the customer demand for the non-critical products. The availability of spools was originally not considered to be a major production issue. The major production issues were considered to be the sequencing of products and the gross capacity of the flow lanes. The development of the simulation model required modeling the spool returns from the customer. Analyzing the spool return data, including fitting a distribution function, indicated that the availability of customer spools was a much more significant problem than originally considered. The variation in the spool returns caused greater delays in production than the sequencing of products or the availability of "open" capacity gaps.

Simulation output was able to identify critical customer spool issues as well as identify specific flow lanes capacity utilizations. Without the simulation, and understanding the interactions between the different components in the system, the designed future state would not have yielded the benefits the manufacturer sought during the lean implementation process. Identifying these specific issues allowed the manufacturer to address logistical and capacity problems prior to the final implementation of the new production system.

3.2 Case Example #2: Fabricated and Assembled Products

The second industry case example concerned the lean implementation process at a fabrication and assembly facility. The simulation model developed for this manufacturer addressed several deficiencies of lean implementation process including the integration of random and structural variation into the validation of the future state map as well as identifying the effects of component interactions, specifically related to synchronization of production as well as sequencing of the products in the flow lanes, on the ability to meet customer demands based on the production plan.

The lean initiative for this manufacturer involved developing a new facility layout, based on product flow lanes, that would include all operations necessary to completely fabricate and assemble the final product. The organization and design of the flow lanes was based on gross equipment capacity and historical production analyses. The production system equipment layout was organized so that the majority of products could be completely processed in one flow lane but, due to equipment processing and capacity limitations, some products needed processing in more than one product flow lane. The complete production process required the manufacture of two separate subcomponents and the assembly of these subcomponents into the final product which was then shipped to the original equipment manufacturer. The process flow is illustrated in Figure 3.

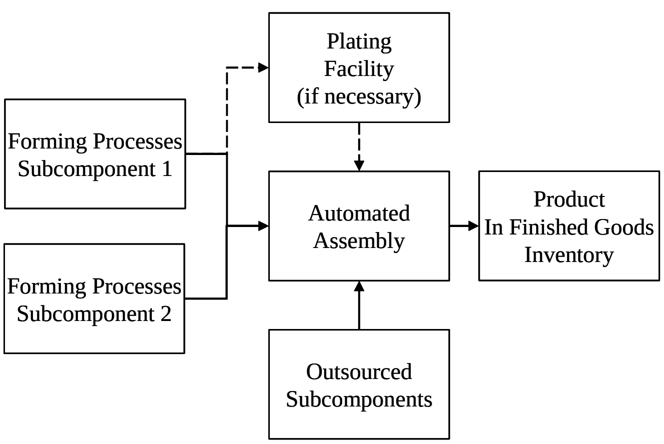

Figure 3: Product Flow

The manufacturing process described might appear to be fairly uncomplicated and easily synchronized. However, bottlenecks were created in the process by the fact that the equipment used to fabricate and assemble the subcomponents and final products operated with different processing speeds and capacities. Structural variation was introduced into the production system by the requirement that some, but not all, of the subcomponents undergo plating at an outside vendor as well as the outsourcing of other subcomponents.

The manufacturer employed a production planning process that assigned the products to the flow lanes based on flow lane capabilities and product requirements. The production was scheduled based on a repetitive cycles. The assignment of product to the product lanes was based on gross capacity and did not take into account any of the dynamics of the production system such as the interaction between the processes and variability introduced into the system due to differences in equipment processing capabilities.

While developing the future state for this system, it was evident that there were some questions that could not be addressed by performing a deterministic capacity analysis. These questions included:

1. Did the variability in equipment processing times effect the ability to adhere to the production plan?
2. Did the inter-product lane travel effect the production plan?
3. Were there other interactions that are occurring between the products that were not evident by performing a gross capacity analysis?

The simulation model was developed to investigate how the different sources of variation, including processing and arrival times, affected the ability of the production system to meet the production plan. A main function of the simulation was to identify occurrences when the assembly process had to be halted or modified due to lack of subcomponents. The simulation was able to not only to identify these occurrences, but through the processing logic, simulate decisions that would be made on the production floor to adapt to shortages. The identification of the root causes for the subcomponent shortages allowed the manufacturer to identify equipment or processes that needed improvement.

3.3 Case Example #3: Inventory Management and Outsourcing

Lean concepts are also applied to supply chains. This case example has to do with inventory management in a short, local supply chain. Outsourcing a painting operation in the middle of a production process resulted in complex inventory management issues. Part flow in the process was delayed by the need to wait for periodic shipments to and from the outsourced operation. Since not all parts waited the same amount of time, outsourcing is a source of structural variation. Customer demand was random. Variation due to batching was a significant issue. The future state was defined in significant part by the number of totes in the system.

An automotive parts supplier manufactured parts in three steps: molding, painting, and assembly. There are eight part types distinguished from each other only by their color. Parts were transported throughout the process in totes of 32 parts of the same color. Any tote could be used for any color part. The process was complicated because the painting step was outsourced to a company near the automotive parts supplier and performed in batches of 192 parts. Transportation strategies between the manufacturer and the painting contractor were at issue. The molding process produced 32 parts at a time, the number of parts in a tote. The assembly operation produced 48 parts at a time, the number of parts per shipping container.

The number of totes needed to be minimized since each tote was expensive and required a significant amount of storage space. The lean supply chain team had responsibility for determining the number of totes. The production team was concerned that the number of totes determined by the lean supply chain team was too high.

The following issues could not be addressed by the lean process.

1. What is the procedure or algorithm for determining the number of totes?
2. How much inventory of each color part should be kept and where?

Because the future state value stream map is a descriptive model that could not be analyzed, it was not possible to tell what system components were necessary for operations but missing from the design. Constructing and validating the simulation model identified that the system needed to be driven by customer demand that was satisfied from a finished good inventory. A work-in-process inventory in front of the painting operation needed to be established and controlled. Otherwise parts in totes simply flowed through the production process.

A customer demand would create the need for additional work at each of the three production steps to replace the parts delivered from the finished goods inventory (FGI). A target FGI for each part color was set based as the 99% point of the distribution function modeling the daily demand for that part color.

Simulation results showed that only about 50% of the totes originally though necessary would be required.

4 SUMMARY

Lean is a necessary but not a sufficient approach to analyzing production system issues. Deficiencies in the lean approach arise because it is an deterministic method and it uses only descriptive value stream maps to model production operations. Simulation provides a method for including random and structural variation in models, identifying at least a very good solution to production system issues before implementation by examining a variety of alternatives, and assessing the effects of the interaction of system components.

Based on our experience performing the case studies discussed above and numerous others, we have found that a "Yes" answer to any of the following questions indicates that simulation is needed to supplement lean methods for the analysis and design of a production system:

1. Are multiple part types produced?
2. Are parts shipped on days when they are not produced?
3. Are some operations performed off-site?
4. Does the customer return shipping containers that need to be re-used by the production system?
5. Is there significant downtime or any other significant disruption in any production operation?
6. Is the production process ever starved due to a lack of raw material?
7. Is inventory storage space highly restricted?

A variety of industry based case studies have shown how simulation is needed to extend the lean process and overcome its deficiencies when the answer to one or more these questions was "Yes".

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