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SIMULATION AS A TOOL FOR CONTINUOUS PROCESS IMPROVEMENT

Mel Adams
Paul Componation
Hank Czarnecki
Bernard J. Schroer

University of Alabama in Huntsville
Huntsville, AL 35899, U.S.A.

ABSTRACT

Simulation offers a powerful tool to support the continuous improvement process. This paper presents a description of the tools of lean manufacturing, the steps in the continuous improvement process and two case studies where simulation was used in the continuous improvement.

1 INTRODUCTION

In the early 1900's, Henry Ford introduced a new manufacturing system - mass production. Ford's philosophy was to build a small, strong and simple car at the lowest cost. The key elements of the Ford system were conveyors, division of labor, and an integrated supply chain (Imai 1986). The conveyors moved cars through the assembly process with work coming to the worker rather than the worker going to the work. Division of labor organized the assembly process into simple, repetitive tasks. Each worker performed a single task whereas before each assembled the entire assembly. The integrated supply chain provided parts and materials to the assembly line. Ford reduced deviation in parts, thus assuring that parts would fit together properly.

The Toyota production system evolved from the Ford manufacturing system. Managers and employees learned to question the need for every work sequence, every piece of in-process-inventory, and every second that people, material and machines are idle. As a result, not only does production increase, but quality increases when people learn to identify and eliminate waste (Ohno 1988 and Monden 1993).

Lean manufacturing has evolved from the Toyota production system. Lean manufacturing is a way of thinking, a culture where all employees continuously look for ways to improve the process with the philosophy of eliminating all non-value added activities. The essence of lean manufacturing is to compress time from receipt of an order through receipt of payment. Compressing time yields greater productivity, shorter delivery times, lower costs, improved quality, and increased customer satisfaction. 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).

2 LEAN MANUFACTURING TOOLS

The tools of lean manufacturing are given in Figure 1 (Lean Manufacturing Handbook 1999). The foundation of lean manufacturing includes the following tools:

- 5 S's - Various house keeping activities are often used first in adopting the continuous improvement way of life and are:
  - Sort out what is unneeded
  - Straighten what must be kept
  - Scrub everything that remains
  - Stabilize - spread the clean routine and provide employees with training and time to improve their work areas
  - Standardize - establish a cleaning schedule; this requires self-discipline
- 5 Why's - When a problem is found ask "why" five times. Repeating why five times helps find the root cause of the problem rather than merely responding to symptoms.
- Visual Factory - Information is made available and understandable at a glance for each operator to see and use in achieving continuous improvements (Grief 1991).
- Focus groups - Process improvement teams are trained and responsible for detecting waste. Departmental barriers are eliminated

and replaced with cross-functional teams that study a process and then immediately implement improvements.

A brief description of the remaining lean manufacturing tools in Figure 1 is:

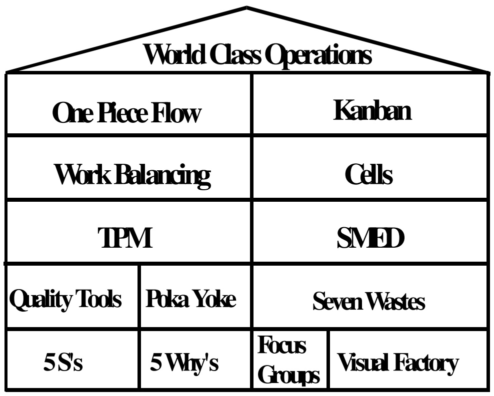


Figure 1: Lean Manufacturing Tools

- Quality Tools - Typical quality tools are flow charts, frequency histograms, Pareto diagrams, cause and effect diagrams, and control charts.
- Poka Yoke - Poka Yoke are simple, low cost devices that prevent defective parts from being made or passed on in the process. Poka Yoke eliminates defects by eliminating mistakes (Shingo 1986).
- Seven Wastes - Ohno defines waste as all elements of production that only increase cost without adding value the customer is willing to pay for. The seven wastes of manufacturing are:
  - Waste of producing more product than needed
  - Waste of inventory - any supply in excess of required to produce product
  - Waste of waiting - idle operator or machine time
  - Waste of motion - movement of people or machines which does not add value
  - Waste of transportation - any material movement that does not directly support value added operations
  - Waste of making defective parts
  - Waste of processing - any process that does add value to product
- TPM - Total Productive Maintenance consists of a company wide equipment maintenance program that covers the entire equipment life cycle and requires participation by every employee (Nakajima, 1988).
- SMED - Single Minute Exchange of Dies is a system that allows the mixing of production without slowing output or creating higher costs from waste of setup. (Shingo, 1983).
- Work Balancing - Work balancing maximizes operator efficiency by matching work content to TAKT time. TAKT time is the rate at which the customer requires the product and is computed as:

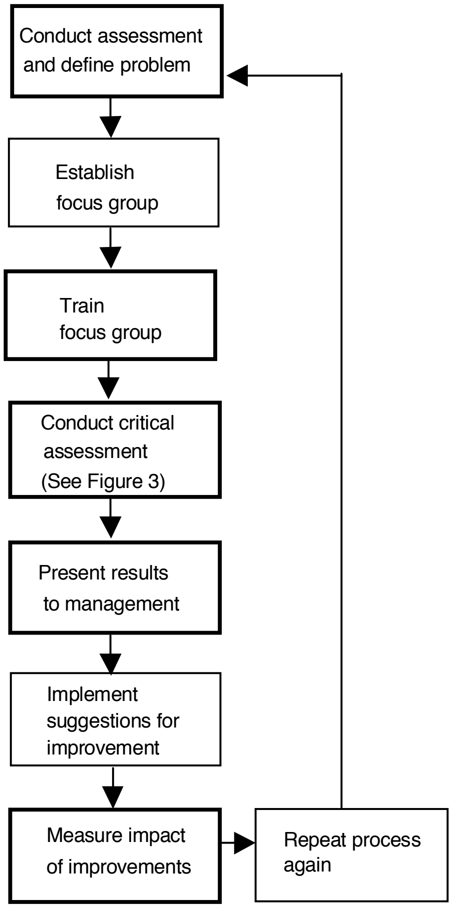
$$\text{TAKT time} = \frac{\text{Available work time per day}}{\text{Daily required customer demand in parts per day}}$$

- Cells - Proper placement of machines is essential. Benefits of good cell layout are reduced inventory, balanced work, less walking time and an improved work area.
- One Piece Flow - To minimize work-in-process, operators should focus on one part through the process before starting the next part (Sekine 1990).
- Kanban - A kanban system is an information system that controls (pulls) the required parts in the required quantities at the required time (Schonberger 1982).

3 CONTINUOUS PROCESS IMPROVEMENT

Figure 2 outlines the steps in the continuous improvement process. The champion starts the process by requesting a process assessment. After reviewing the results, the champion sets an aggressive goal, forms a focus group and schedules a continuous improvement, or Kaizen. A typical schedule for a Kaizen event is:

- 1/2 day training on lean manufacturing, the use of the tools, team building and brainstorming techniques
- 3 1/2 days to conduct critical assessment (See Figure 3)
- 1/2 day to present results to management



Note: Bold boxes indicate those steps where simulation can be used to support the continuous improvement process.

Figure 2: Steps in Continuous Improvement Process

Next, a facilitator trains the focus groups in the tools of continuous improvement discussed in Figure 1. The focus group then conducts a critical assessment of the manufacturing process. The steps of the critical assessment are given in Figure 3.

By the morning of fourth day, the focus group has identified many opportunities for improvement. The group then documents the results of the critical assessment and prepares its presentation. During the afternoon of the fourth day, the focus group presents its findings to the champion.

The continuous improvement process demands immediate implementation of the selected opportunities. Also, the process requires that the impact of the improvement be measured and compared with the manufacturing process before implementing the improvements.

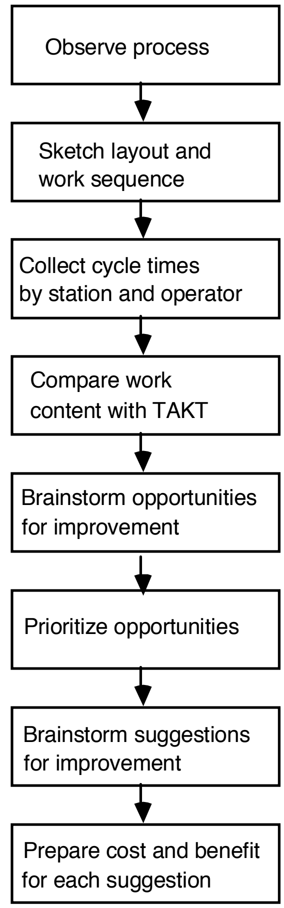


Figure 3: Steps in Critical Assessment

4 SIMULATION SUPPORT TO CONTINUOUS PROCESS IMPROVEMENT

Simulation can be used to support the continuous improvement process as shown in Figure 2. Several of the obvious steps where simulation can support the process are:

- Step 1: Conduct assessment, define problem and set aggressive goal - One of the most obvious ways to use simulation in continuous process improvement is as an assistant to the champion in identifying problems in the manufacturing process. Several typical simulation metrics for identifying problems are large work-in-process, low machine and operator utilizations, excessive delays and 100% busy machines and operators. Armed with these problem areas, the champion can then prioritize the problems and select those with the greatest payoffs. As a result, the champion can provide the focus group with a specific goal.

- Step 3: Train focus group - It is well known that simulation is a valuable training tool. This is especially true since operators generally represent over one-half of a focus group.
- Step 4: Conduct critical assessment - The focus group can use simulation to evaluate the impact of various opportunities for improvement. Ideally the group can use the previous developed simulation model to evaluate the alternatives.
- Step 5: Document opportunities for improvement - The results of the simulation can be used by the focus group in documenting the opportunities for improvement.
- Step 7: Measure impact of improvements - Once a suggestion for improvement has been implemented, the simulation model can be modified to include the suggestions and then run to measure the impact.

5 CASE STUDIES

The manufacturers in the following two case studies are clients of the University of Alabama in Huntsville (UAH) Manufacturing Extension Partnership (MEP). The MEP is a national network to assist manufacturers to become more competitive. More than eighty state MEP centers address the critical needs of manufacturers. The MEP in Alabama is administered by the Alabama Technology Network, Inc., (ATN), a not-for-profit corporation headquartered in Birmingham. Ten regional centers have been established to provide assistance to over 6,700 manufacturers in the state. UAH is the ATN Region 1 Center serving 1100 companies in six North Alabama counties. Both manufacturers requested anonymity.

5.1 Commercial Manufacturer

This manufacturer produces over two million units annually in a twenty-five year old plant with over 200,000 square feet of manufacturing space and 800 employees. Over the years, UAH has assisted the company prepare its continuous process improvement handbook and participated in several critical assessments.

The company is currently expanding worldwide. UAH developed several simulation models of the manufacturing lines for the proposed international plants which were used by the company's focus group in the design of the lines. The focus group consisted of the manufacturing manager, a manufacturing engineer, a UAH engineer and a UAH change management specialist. The focus group had access to a UAH engineer trained in constructing simulation models. The simulation models were written in ProModel (Heflin and Harrell 1998) and overlaid on a scaled factory floor layout. The model was verified by removing all cycle time variation and running a single transaction through the model. The transaction time in the system was then compared with the calculated system time. Model validation was accomplished through an interactive process between company staff and the modeler. The model animation feature provided great insight in the model behavior. Model analysis consisted of running a baseline and a number of variations to the baseline.

The initial line consisted of two parallel lines with 22 stations per line, one inspection line with thirteen stations, 49 operators and 1185 feet of conveyors. The baseline simulation model was developed of the proposed line and was used by the champion (i.e., the Vice President of International Operations) to identify three problem areas: 1) excessive work-in-process caused by excessive pallets, 2) low operator utilization at several stations and 3) several large station cycle times. The focus group was then charged with the task to identify opportunities for improvement of these problem areas.

Three variations to the baseline simulation model were developed and used by the focus group during the design Kaizens. The hourly production based on the simulation models is given in Table 1. The baseline model closely approximated the theoretical production of the lines. As anticipated, adding station down times reduced production to 117 units per hour. The simulation was then run with a continual reduction in the number of pallets. The pallets were reduced from an unlimited number to 120 with no reduction in hourly production.

Table 1: Simulation Results from Various Model Alternatives

Model alternative	Hourly production
Theoretical	200
Baseline run with no station down time	194
Station down time	117
Pallet constraint	119
Cycle time reduction	154

In summary, the use of simulation in the continuous improvement process resulted in:

- An estimated six months reduction in time in the design stage.
- Shorter conveyor lengths and fewer pallets resulting in an estimated $500,000 savings in up-front capital equipment investment.

An interesting outcome of the design Kaizens was an entirely new design of the lines which was labeled the radical design. At the request of the champion a simulation model was developed of the new design. A comparison of this design with the baseline design is given in Table 2. Production remained the same with thirteen fewer operators, fewer machines, and a 50% reduction in conveyor distance.

Table 2: Comparison of Radical Design with Baseline Design

Parameter	Baseline design	Radical design
Number of lines	2	1
Number of operators	49	36
Floor space		25% less
Major equipment not needed		Several machines
Conveyors		50% less
Production	194	200

5.2 Aerospace Manufacturer

This company manufactures large high-precision aerospace and defense components in small lot quantities. The company was founded in the 1980s and has over 75,000 square feet of manufacturing space and 450 employees.

Strategic planning by UAH identified process improvement as a key to better on-time delivery, more capacity and profitability goals. An outside consultant group along with UAH helped the company identify ten problem areas. In its first three-day Kaizen event the focus group evaluated part handling and routing. Parts were being moved thirteen times over 1600 feet. The Kaizen event relocated two operations, set up a new staging area and reduced total travel distance to 160 feet.

A second problem area was the scheduling of work at two large gantry milling stations. These stations were primarily used to machine 12 feet by 20 feet aluminum panels. The first station roughs a panel in 40.5 hours. The panel is then transferred to one of two milling machines at Station 2, which finishes a panel in 110 hours. Station 1 is interrupted on an irregular basis when a rush job needs to be processed. The problem is the impact on production resulting from these small rush jobs.

The champion of this effort was the vice president for manufacturing. The focus group consisted of the scheduler, a manufacturing engineer, a UAH engineer and a UAH change management specialist. A simulation model was developed in ProModel and overlaid on a scaled factory floor layout. The model was verified by removing all cycle time variation and running a single transaction through the model. The transaction time in the system was then compared with the calculated system time. Model validation was accomplished through an interactive process between company staff and the modeler. The model animation feature provided great insight in the model behavior. Model analysis consisted of running a baseline and a number of variations to the baseline.

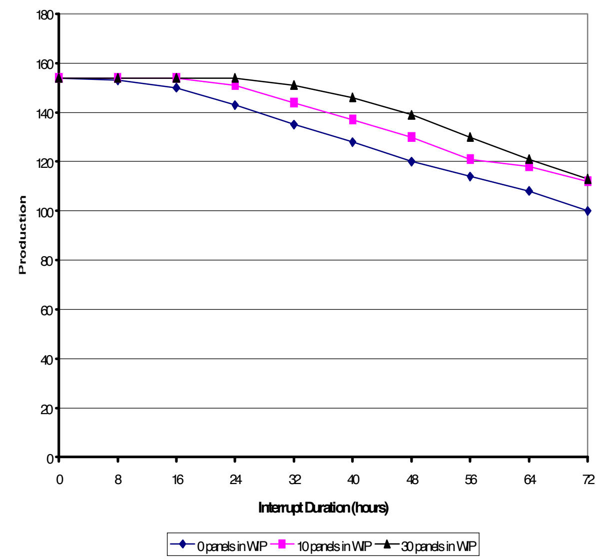


Figure 4: Production with Various WIP

Figure 4 shows the production of panels as a function of interrupt time for the small rush jobs. Table 3 gives the corresponding machine utilizations. The three graphs are with no work-in-process at Station 2, ten panels in WIP, and thirty panels in WIP. An analysis of the results by the focus team indicated:

- Small jobs can interrupt Station 1 without impacting the production of panels provided there is WIP at Station 2.
- The impact of an interrupt at Station 1 on production is a function of WIP at the Station 2. That is, the larger the WIP at Station 2, the greater the allowable interrupt. For example, an interrupt of sixteen hours plus forty-eight hour changeover has no impact on throughput

when WIP is ten panels, and an interrupt of twenty-four hours plus forty-eight hour changeover has no impact on throughput when WIP is thirty panels.

- The MRP system need not be used for scheduling Machines 1 and 2.

Table 3: Machine Utilizations

Interrupt (hours)	Production	Utilization(%) Station 1	Station 2 Machine 1	Station 2 Machine 2
0 panel WIP				
0	154	100	100	100
8	153	100	100	100
16	150	100	99	96
24	143	100	95	91
32	135	100	90	86
40	128	100	85	81
10 panel WIP				
0	154	100	100	100
8	154	100	100	100
16	154	100	100	100
24	151	100	99	97
32	144	100	94	93
40	137	100	90	87
48	130	100	85	82
30 panel WIP				
0	154	100	100	100
8	154	100	100	100
16	154	100	100	100
24	154	100	100	100
32	151	100	100	98
40	146	100	96	93
72	113	100	75	72

6 CONCLUSIONS

Simulation was used in the two case studies to support the following continuous process improvement steps:

Firm A
- Conduct assessment
- Conduct critical assessment
- Present results to management
- Measure impact

Firm B
- Conduct critical assessment
- Present results to management

Observations of the two firms in the case studies revealed:

- Top management was driving major change in both organizations with strong management commitment and support. Continuous improvement, radical and incremental, was one key to the strategic plan and the intended rate of change. Simulation indicated ways to change faster.
- Firms are believers in the continuous improvement process. Each firm has a full time process improvement coordinator who regularly conducts Kaizens. Firm A was very experienced in lean manufacturing having conducted several hundred Kaizens in a successful systematic effort to double production. Although just beginning to use Kaizens, Firm B was known for its low costs achieved by driving each product down a steep learning curve. Thus, both firms constantly experimented to find better methods of doing things.
- Although both firms had on-site manufacturing engineering groups, neither firm had any experience with or capability in simulation. Both firms needed an introduction to and assistance in developing the simulations. Firms A has since bought its own ProModel and has been trained by UAH in model development. UAH time to develop the simulation models in ProModel was:
    - Firm A 116 hours for four models
    - Firm B 8 hours for one model
    - Firm A 16 hours for radical design model
- Both managers gained insights otherwise available only through expensive trial and error. Firm A avoided major mistakes in plant construction and startup, and Firm B corrected key assumptions about scheduling and routing that were wasting equipment and staff time. In each case, the simulation results helped change the managers' mental models of the way the process was best managed.

In summary, the following conclusions are made about the relevance and application of simulation in the continuous improvement process:

- Process simulation can be used to support several key steps in the continuous improvement process. It is most useful at the design stage, the assessment stage, and for presenting results to management. Simulation is another complementary tool of, not a substitute for continuous improvement. However, it cannot do the essential work of the focus groups: identifying opportunities for improvement and actually making the changes in the process.
- Although firms can start the continuous improvement process and make major gains without simulation, simulation models may be most effective if developed, verified and validated as early in the change process as possible. Used wisely, simulation makes everyone smarter about what and when to change.
- To be most effective, simulation models should be developed that apply continuous improvement concepts. For example, rather than merely modeling the total cycle time for each machine, much more insight can be gained by separating run time, setup and changeover times, downtime, break times, defect rates, and material handling into and out of the machine.
- For new situations, basic, simple models of the process are a good way to start. They demonstrate quick results to decision makers, show that there is much more potential for improvement than imagined, and can help managers focus on the real issues rather than continuing to fight fires. For Firm A, the simulation prevented more wasted effort on a fatally flawed design. The key to quick, relevant results is to make a few key assumptions that simplify the simulation model to minimize programming time.
- Using the simulation effectively during a Kaizen event requires immediate access to a trained simulation specialist. This person must rapidly modify the simulation model so the focus group can evaluate various suggestions for improvement. Some suggestions may be testable with quick, minor modifications to a single input variable, while others may take several hours to alter the layout and design of the model.
- Interpreting the results with management, at least in the first few applications, can benefit from the perspective of a change management specialist who understands both the capabilities of simulation and the firm's strategy, goals, value chain and market drivers. This individual can often help executives discuss the results presented by technical experts and focus group members. Cross-functional, system and strategy implications may not be obvious to any of these groups. This person can also help guide the decisions about how to extend the simulation or what part of the process to simulate next.
- Overlaying the simulation model on a scaled layout of the manufacturing floor provides the focus group with a sense of reality to the operation of the model. Animation features of the simulation give the focus group the ability to see the factory in operation and provides tremendous insight. If a picture is worth a thousand words, the simulation's to-scale motion picture of the line in action is worth a million words.

ACKNOWLEDGMENTS

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AUTHOR BIOGRAPHIES

MEL ADAMS is a senior research scientist in the Center for Automation and Robotics at the University of Alabama in Huntsville. He holds a Ph.D. in Strategic Management and MBA from the University of Tennessee. His research focuses on strategic change and entrepreneurship.

PAUL COMPONATION is an assistant professor in the Industrial and Systems Engineering Department at the University of Alabama in Huntsville. His areas of expertise are human factors, operations improvement, engineering economy, and systems engineering. He holds a Ph.D. in Engineering from West Virginia University.

HANK CZARNECKI is a research scientist in the Center for Automation and Robotics at the University of Alabama in Huntsville. His areas of expertise are continuous process improvement, plant and manufacturing cell layout, and just-in-time systems. He has completed coursework for the Ph.D. in Industrial and Systems Engineering from the University of Alabama in Huntsville.

BERNARD J. SCHROER is director of the Center for Automation and Robotics, a professor in Industrial and Systems Engineering, and Associate Vice-President for Research at the University of Alabama in Huntsville. He has a Ph.D. in Industrial Engineering from Oklahoma State University and is a registered professional engineer. His areas of research are manufacturing systems, systems simulation, and continuous process improvement.