AC 2012-5146: A METRIC-BASED, HANDS-ON QUALITY AND PRODUCTIVITY IMPROVEMENT SIMULATION INVOLVING LEAN AND SIGMA CONCEPTS FOR FIRST-YEAR ENGINEERING LAB STUDENTS

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A Metric-Based, Hands-On Quality and Productivity Improvement Simulation Involving Lean and Six Sigma Concepts For First-Year Engineering Lab Students

Abstract

A new hands-on quality and productivity lab involving lean and six sigma concepts for first-year engineering students was created at the First-year Engineering Program within the Engineering Education Innovation Center at The Ohio State University. The quality and productivity lab is approached in three phases. First, students are presented introductory material in the regular (non-lab) class period prior to the lab session. This first class session starts with an overview of typical organizational departments and functions, the importance of engineering as it relates to management and production, and how lean practices can impact profit. Students are also assigned roles for the lab activity and given basic information and terminology about lean, sigma, and production operations. Students are also assigned a pre-lab exercise to reinforce roles, terminology, and concepts.

At the start of the lab period, the second phase of the quality and productivity hands-on lab, students immediately assume their roles in one of two competing value-adding organizations or as the organizations’ customers. The mock organizations produce a real product with six variants. Students run the line in this relatively inefficient default setup and record data. Students must consider the results of key metric calculations from data collected in making process improvements through facilities layout changes, personnel changes, line balancing, converting from a push to pull system, improving communications, etc. Students are then left on their own to cooperatively deliberate, problem solve, and reorganize their production systems to achieve profitability using the terms, concepts, and analytical approaches they have gleaned. After a second production run, data is entered into the scorecard again and key metrics are again calculated. Production lines typically improve and show profit in the second run.

In the third phase of the quality and productivity lab, students complete a team technical writing assignment to report the results of the lab and discuss further improvements. Students create visual aids representing the layout and performance of the lines and discuss hypothetical situations gauging the depth of their understanding of quality, productivity, lean, and sigma concepts.

Student survey feedback indicates students favor the lab and enjoy the activities and problem-solving with peers. Instructional staff training required on production systems concepts for those lacking industrial engineering backgrounds, lab setup and parts procurement for the product assemblies, and classroom and lab logistics preparation and management present the most significant challenges to running the quality and productivity lab.

Introduction

The First-year Engineering Program within the Engineering Education Innovation Center at The Ohio State University offers incoming engineering students a choice of a two-course Fundamentals of Engineering standard track, a two-course Fundamentals of Engineering for
Scholars track featuring students in a living/learning community, and a three-course Fundamentals of Engineering for Honors track. All three of these course sequences feature integrated curricula and activities that cover engineering graphics and computer-aided design (CAD), problem solving through computer programming, oral and written technical communications, hands-on, active lab sessions that sample various disciplines in engineering, and a term-length, cornerstone design-build project. The hands-on labs feature topics covered over one to two lab sessions in the first terms, preceding one of six possible term-length cornerstone design-build projects in the final term of each of the course sequences.

The hands-on labs are regularly replaced and updated to keep curricula and activities current with modern engineering trends and challenges. Recent new labs in standard and Scholars tracks feature a focus on global and “grand challenge” engineering topics such as sustainability and green engineering, including a two-session solar cell lab, a hydrogen fuel cell lab, and a quality and productivity improvement lab.

Background, Development, and Piloting

The First-year Engineering Program in the Engineering Education Innovation Center has a number of physical simulation laboratories that have been designed to provide first year engineering students with a hands-on experience with a variety of engineering principles and methods. One such lab was casually called the ‘Camera Lab’ as it involved the assembly of a disposable Kodak Camera.

The learning constructs in this lab primarily revolved around push versus pull type production and inventory management systems with a single product variant. In short the learning constructs were somewhat narrow and limited albeit useful. The leadership of the First-year Engineering Program desired to update and expand this lab.

An Integrated Systems Engineering faculty member intimately knowledgeable about state of the practice integrated lean and six sigma training constructs, methods, approaches, and, in particular, learning labs and his protégé graduate student were asked use their expertise to assist in the design and development of a new and improved lab that would broaden and deepen the learning constructs.

There are many training tools and methods employed to introduce the concepts, principles and methods of lean and six sigma. The initial approach was to significantly tailor or reengineer the ‘stickle brick’ physical simulation originally developed for the Integrated Lean Six Sigma Certification Program at the Department of Integrated Systems Engineering to meet the constraints and requirements of the first-year engineering setting. Bristle blocks were initially used for the basis of a product representation. There are many versions of this simulation in the market, and consideration of these was the basis of the stickle brick version developed prior to application in this first-year engineering setting.

An enhanced lab introductory lecture module focusing on the role of engineers in quality and productivity improvement was designed and developed. Lean and six sigma were the focus as current state principles and methods used to drive quality and productivity improvement.
physical simulation lab then followed the orientation presentation. Both the presentation and the lab were tested several times at the main Columbus campus and at the Newark, Ohio campus. Formal student evaluations and informal instructor feedback and conferences were utilized to refine and enhance the instructional design over several iterations.

After running several informal partial and formal complete pilots of the lab activities and the lab as a whole, faculty and developers of the quality and productivity lab agreed to make further modifications. There were a series of justifications for these changes.

First, there was a disparity in time allotted for the professional version of the simulation from which the lab was adopted. In addition, experience of participants and other characteristic differences between professional participants and freshman post-secondary students needed to be further addressed. There was also a necessity to accommodate instruction by non-expert faculty from other fields of engineering. It was also agreed that students would benefit from a real product rather than an abstract product represented by bristle blocks to serve as the assembly.

After conducting a program-wide brainstorming session soliciting suggestions from all current students, a basic gate valve assembly featuring three model variants (sweat, threaded, and compression attachment types) with mostly interchangeable parts and two handle colors for a total of six possible product variations was selected, as seen in Figure 1 with just one handle color. This product type was selected for ruggedness, parts interchangeability, design stability, and availability.

![Gate valve models](image1)

**Figure 1:** Gate valve models from left to right: threaded, compression fitting, and sweat.

Finally, there was also a general call to limit the number and scope of concepts students were expected to learn to allow for more depth of understanding with a slightly smaller set of terms and concepts.
Learning Objectives

- Describe how organizations function and are organized
- Demonstrate an understanding of the challenges organizations today face in a very global and competitive marketplace
- Apply fundamental principles of quality and productivity improvement
- Apply fundamental principles of lean and sigma such as push versus pull, single piece flow, inventory management to achieve quality AND productivity
- Complete a balanced scorecard and use it to improve quality and productivity
- Identify the voice of the customer and describe what the customer wants and how the customer defines quality

Lab Overview

The quality and productivity lab is approached in three phases. First, students are presented introductory material in the regular (non-lab) class period prior to the lab session. Students are introduced to a typical corporate organizational structure. The importance of engineering and interdependence of engineering with key organizational and managerial functions is stressed, from product design, support, engineering economics and manufacturing to data collection and instrument setup, data analysis, and decision support. Students are shown how incremental improvements in efficiency and cost of operations can greatly affect a company’s profitability. Students are introduced to concepts such as lean practices, sigma, and how the customer defines value. Students are provided with an overview of sequential production systems, terminology and upcoming lab logistics. Key concepts and terminology are summarized as follows:

- Typical organizational departments and functions
- Overlap between engineering and other departments and functions
- Relationship and importance of engineers in an organization
- Engineering support of decision-making
- Value-adding Systems’ inputs from upstream systems and outputs to downstream systems
- Impact of engineering (particularly in terms of production) on profit and expenses
- Lean minimizes waste
- Types of waste
- Six Sigma minimizes variation
- Sources of variation
- Sigma and Lean as it pertains to the Normal distribution
- Customer defines value with order accuracy, timeliness, and quality
- Sequential workflow
- Sources of income and expenses
- Push versus pull systems and Kanban discipline and information flow
- Line balancing, cycle times, bottlenecks, capacity versus demand

Students are then provided thorough descriptions of roles and assembly instructions. Each student is assigned a role for the production simulation. Roles are shown in Figure 2.
Students are then tasked to complete a pre-lab exercise to reinforce roles, terminology, and concepts. Following are the questions posed to the students in the pre-lab assignment:

1) What is your assigned role and what are your responsibilities / expectations? What data (if any) do you collect and report?
2) What are the assembly operations for the M300 series gate valve? What do you think would take the longest? The shortest? What considerations are there if big differences between individual operation times arise?
3) How do you take the cycle time of an operator?
4) What are valuable to the customer?
5) What are the 8 forms of waste? Provide examples.
6) What comprises a high service level for the customer?
7) What causes low profitability? What leads to high costs and low service level?
8) What can be done to remedy these types of issues?

The hands-on lab session comprises the second phase of the quality and productivity curricula. At the start of the lab period, students immediately assume their roles in one of two competing value-adding organizations in the initial or default layout, or as the organizations’ customers at the front of the classroom. The initial layout is shown in Figure 3.

<table>
<thead>
<tr>
<th>ROLE</th>
<th>QUANTITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operator</td>
<td>9</td>
</tr>
<tr>
<td>Operations Manager</td>
<td>1</td>
</tr>
<tr>
<td>Transporter</td>
<td>1-2</td>
</tr>
<tr>
<td>Quality Control</td>
<td>1</td>
</tr>
<tr>
<td>Timer/Analyst/IT/Data Collector</td>
<td>2-3</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>14-16</strong></td>
</tr>
<tr>
<td>Customers (external to organization)</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total Per Line</strong></td>
<td><strong>16-18</strong></td>
</tr>
</tbody>
</table>

Figure 2: Student roles and quantity per production line.
Figure 3: Initial classroom layout of two competing organizations with their respective customers where student positions are indicated with colored ovals and abbreviated role labels within each oval. Rectangles represent lab tables.

The lab schedule for a 108 minute lab session transpires as follows:

<table>
<thead>
<tr>
<th>Agenda Item</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assembly Instructions, Roles, Responsibilities, Data Collection</td>
<td>15</td>
</tr>
<tr>
<td>2. Trial Run, 1-2 finished pieces</td>
<td>05</td>
</tr>
<tr>
<td>3. Run Cycle 1, Push</td>
<td>10</td>
</tr>
<tr>
<td>4. Complete Scorecard, Reverse Cycle/Disassemble/Reinitialize</td>
<td>10</td>
</tr>
<tr>
<td>5. Debrief, Data Analysis, Root Causes, Improvements, Group Discussion</td>
<td>15</td>
</tr>
<tr>
<td>6. Consultant Discussion, Pull Revelation, Reconsider Layout, Line Balance, Etc.</td>
<td>20</td>
</tr>
<tr>
<td>7. Run Cycle 2, Pull</td>
<td>10</td>
</tr>
<tr>
<td>8. Complete Scorecard, Reverse Cycle/Disassemble/Reinitialize</td>
<td>10</td>
</tr>
<tr>
<td>9. Discussion, Memo Notes, Dismiss</td>
<td>05</td>
</tr>
<tr>
<td>Total</td>
<td>1:40</td>
</tr>
</tbody>
</table>

The mock organizations produce a real product with six variants. Students run the line for up to 10 minutes in this relatively inefficient default setup and record data. Customers enter orders from an otherwise secret ordering schedule and record product orders that are late, defective, or otherwise incorrect. Timers record lead time, cycle times, and take general notes. Operations
managers enforce order procurement and keep a coordinating eye on the entire organization and take general notes as well. Quality control personnel randomly inspect a single item per order for defects and record their findings.

At the conclusion of the first production run as a sequential push system, the collected data is populated into the first five sheets of a pre-formatted and selectively protected (to prevent accidental tampering) six-sheet spreadsheet, where the sixth sheet is fully-automated, self-populating calculated scorecard. Students must use the scorecard and consider the results of key metric calculations in making process improvements through facilities layout changes, personnel changes, line balancing, converting from a push to pull system, improving training and communications, etc. Students are then left on their own for 20 to 30 minutes in a cooperative, open-ended problem-solving environment to deliberate and reorganize their production systems to attain profitability with minimal interference from instructional staff. Product variations and the associated process deviations must be accommodated. After a second production run for the same duration as the first run, data is entered into the scorecard again and key metrics are again calculated. The most profitable company wins the competition. The mock organizations are not typically profitable in the first production run. Production lines improve in the second run. A majority of lines also turn some profit by the second production run. The scorecard includes expenses for various forms of inventory, personnel, facilities (number of tables occupied by the organization). The scorecard penalizes the organizations particularly heavily for defects, late orders, and incomplete or undelivered orders. A blank scorecard is shown in Figure 4, showing data reporting responsibilities on the far right column. The Appendix contains an adaptation of the information privy to instructional teams and provides detail on backend considerations and potential solutions.
<table>
<thead>
<tr>
<th>Metrics</th>
<th>Cost / Unit</th>
<th>Cycle</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overdue Orders</td>
<td>$150</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Lead Time (LT)</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value Added Time (VAT):</td>
<td>sec</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Operator 1</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 2</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 3</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 4</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 5</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 6</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 7</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 8</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operator 9</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>QC Inspection</td>
<td>sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Value Add (=VAT/LT)</td>
<td>%</td>
<td>#DIV/0!</td>
<td>#DIV/0!</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Defects</td>
<td>$65</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>External Defects</td>
<td>$100</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Materials</td>
<td>$2</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>WIP</td>
<td>$10</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Final Goods</td>
<td>$20</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Space</td>
<td>$200</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>People</td>
<td>$100</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td><strong>Summary</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># Defect Free Deliverables</td>
<td>count</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revenue = $ Received by Customer for On Time and Defect Free Deliverables</td>
<td>$60/valve</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Total Costs = sum of costs</td>
<td>$</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Profit = Revenue - Total Costs</td>
<td>$</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Defect Free Deliverables Received/Total #</td>
<td>%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Quality Defect Breakdown

Blue

- M300
- M300S
- M300C

Red

- M300
- M300S
- M300C

Total

count 0 0

Quality and Productivity Improvement Notes (stations, duties, layout, space, employees, Cycle1 to Cycle2, etc.):

Figure 4: Quality and Productivity Lab blank scorecard (one per line).
In the third and final phase of the quality and productivity lab, students complete a team technical writing assignment where they must report on the results of the lab and discuss how the production system could be further improved. Students create visual aids representing the layout and performance of the lines. Students are challenged to discuss hypothetical situations to gauge the depth of their understanding of quality, productivity, lean, and sigma concepts and terminology. The section topics of the technical writing assignment are given to the students as:

Header Information

Introduction

Results and Analysis

1. Create a bar chart of operator times and QC times. Which role is the bottleneck? Which role is the most underutilized?
2. Construct a pie chart of costs incurred. Where does the greatest opportunity lie for improving the process? What is the cost of quality?
3. What is the rate of production necessary to fulfill customer demand?
4. Attach / insert the scorecard.
5. Neatly diagram the new system. You may use PowerPoint. Label stations with sequence numbers. Provide average cycle times. Indicate bottlenecks. Indicate value-adding steps. Indicate personnel. Indicate process flow with lines and/or arrows.

Discussion questions

6. Referencing the diagram, the scorecard, and your analyses above, what problems in your system from the first run need to be addressed in order to meet customer expectations (state customer expectations also)? What are the causes of poor performance? Justify your answers from the scorecard!
7. What issues/problems were and were not addressed in your new system from the second run? How did this new layout contribute better service levels and reduced costs? What further improvements would you make to address remaining issues?

Recommendations and Conclusions

8. Considering specifically the design of the entire M300-series product line (all three models), how could this design be improved to foster a more efficient manufacturing/assembly process?
9. How would the inclusion of the cost of raw materials from your company’s supplier affect the scorecard and what strategy should be used to minimize this cost? Considering this, why does your customer make small, frequent orders?
10. Describe any issues you encountered with the lab and make suggestions as necessary.

Student Feedback

Survey feedback from students was generally positive. Student survey entries indicate that students found the lab activity favorable and were happy to be actively doing and problem solving with peers. Students cited the open-ended and collaborative nature of the in-lab problem solving session where the mock organizations convened to discuss how they could improve production and cut costs. Some students wrote that this was their favorite lab. Other students remarked on enjoying getting insight on the workings of both the product and the production process.
Student outcomes, as gauged from submitted student technical reports, were generally encouraging, with most students completing the writing assignment competently, and students who mastered the material completing the technical writing assignment competently with particularly cogent responses to the hypothetical scenarios presented the final questions of the assignment.

Considerations

Some concerns from running the quality and productivity lab activities include the depth of instructional staff training required on production systems concepts for those lacking industrial engineering backgrounds, lab setup and parts procurement for the product assemblies, and classroom and lab logistics preparation and management.

A key logistical issue in the first phase of the activities is getting student roles assigned and recorded. Student preparation and maturity directly influences lab setup time at the start of the next meeting. There is slack incorporated in the organizational roles to allow for class sizes ranging from 32 to 36 students enrolled.

In the second phase between the actual production runs, a key pedagogical issue concerns instructional team restraint and discipline in allowing for the occasionally chaotic and chattery atmosphere as students deliberate within their organizations to revamp their production layout and activities for the hopefully profitable second run. The preference is for instructional team members to limit their comments to those that address reinforcement of pull/Kanban discipline and warnings of time constraints. Students will, if given the time and independence, eventually reach a few epiphanies in terms of line balancing, facilities layout, and work-in-progress if given the chance to study the scorecard and debate potential remedies.

Conclusion

This paper documents the development, piloting, implementation, and logistics of an Integrated Six Sigma lab for first-year engineering students. This exercise shows students can apply introductory quality and productivity concepts to a simulated production of a real product and realize gains made in profit, quality, and overall production efficiency from applying these concepts actively and cooperatively via problem-based learning while having fun and being engaged.

Acknowledgements

The development and implementation of the Quality and Productivity Lab activities and curriculum materials were made possible by a generous donation from Mr. Richard Belville, an Ohio State Electrical Engineering alumnus. Development, technical expertise, testing and initial piloting were provided by and would not have been possible without the substantial efforts of Dr. Scott Sink and Joe Cerrato of the Integrated Lean Six Sigma Certification Program, from which the lab, activities, and relevant instructional materials were derived, in the Department of Integrated Systems Engineering in the College of Engineering at The Ohio State University. Special thanks go to Lowell Toms and Bruce Trott for their assistance and feedback throughout
development and piloting of this lab. An extra special thanks goes to Seth Guterman, President and CEO at American Valve, Inc. for his time and support, specifically in providing insight to the actual manufacturing processes involved in gate valve production and design documentation used for valve design overviews provided in the curriculum materials for the students’ benefit.

References

Appendix

Quality and Productivity Lab

Training Notes (rough)

Q&P Logistics:

1. Classroom
   a. Review slides up to roles
   b. Have students review roles, select roles, mind quantities of each role
   c. GTA provide assigned roles on printed form from data spreadsheets
   d. Students work on pre-lab to finish off Classroom session, instructional team answers questions, complete pre-lab by beginning of Q&P Lab session, must use Classroom Q&P slides to answer questions

2. Before Lab
   a. Students finish pre-lab by beginning of Q&P Lab session (continued)
   b. Setup lab with initial layout (provided below) (see setup qty's in doc)
   c. Have each station primed and ready to go with one of each variety except colored handles in front of corresponding station (3 of each at stations 1, 3, 5, 7 in most cases)
   d. Students review assembly instructions and roles
   e. Have 1-2 valve bodies marked with tape for Lead Time timing (or have roll of tape ready)
f. Have Customer Alpha, Beta, QC, and Timer forms printed and ready, 2 for each person at those positions (Run 1 and 2!)

3. During Lab
   a. Show role positions slide as everyone is entering and have GTA assist in seating and hand-out data collection sheets to timers, QC, Customers. Define what each timer should track, e.g. Timer 1 does all operators and Timer 2 does all other times. Don’t let anyone but Customers see order sheets.
   b. Run C:\apps\stopwatch\stopwatch.exe file and grab student monitors with SchoolVue to synchronize time.
   c. Show gate valve slide
   d. Go to slide with scorecards and explain what is to be recorded for each key role
   e. Before sample build, confirm initial WIP quantities, one of each model at stations 1, 3, 5, 7. Also confirm production step description and model description (labeled pictures). Customers and Quality Control people need defect guide sheet.
   f. Do sample build with all 3 types with red labels (Have students note initial WIP at the stations)
   g. Reverse build (Use new stock only – don’t use initial WIP at stations for this run)
   h. Run 1 (PUSH operation – before first customer order, build as much as possible)
   i. Instructional team enters orders on class spreadsheet (Customer Alpha sheet only) at the end of run or during the run as Customer Alpha calls out the orders.
   j. Collect WIP, final goods, tables, people data for spreadsheet (before reverse build!)
   k. Have timers etc. enter data in the bright YELLOW cells in the appropriate class spreadsheet tabs. Spreadsheet self populates and calculates automatically from entered raw data.
   l. While data entry is going on have reverse build of run 1 happening
   m. Announce results of run 1 and have teams discussing improvements for run 2 (approx. 20 min. for students to work on their own) before “consultant “ intervention – use slides for PULL description
   n. Run 2 (PULL operation, KANBAN discipline)
   o. Repeat steps above steps for run 2 through reverse build.
   p. Make sure all reverse build is done and all stations are pre-loaded and restored to correct tables with descriptions.
NOTES:

a. There are slides showing issues and potential improvements in yellow boxes that are for students to reference during brainstorming.
b. Push operations: let all stages build from timer start any models they choose until the first order.
c. Pull operation: first stage does not do anything until order is announced and they build only that order and stop until next order. The delivery is made from stock in process in the line. The new material coming from the first stage replaces what is used for order.
d. Two computers may be used to enter the data more quickly. For instance, #1, Inc. and the GTA may enter their data on the podium desktop while #2.com and the UTA may enter data on the desktop at the first table. The GTA would then be responsible for consolidating the two spreadsheets before emailing the students.
e. Lead time is measured using a piece of tape on the body from the time that the model is started until that completed valve is delivered.
f. Divide the lab groups into lines such that team E is the only one split between the two lines in a lab. Let team E decide which line to write the memo about.
g. When students combine steps in the second run, timing of operator steps can be based on the new combined steps. They don’t need to be tracked based on original nine steps. The important thing is that all value-added operations are timed and recorded as operations. E.g., 9 operations were reduced to 7 operations, and only times for operations 1-7 were populated in the spreadsheet.

4. After Lab
   a. Send fully populated multi-tab spreadsheet to students

See the schedule below. There is much time allotted for deliberation/process improvement between runs (45 minutes!) and still some slack (100 minutes scheduled – 8 unscheduled minutes out of 108).
Schedule

Activities scheduled for this lab are tightly constrained. It is important that all students know their roles, have reviewed common process issues and remedies, and follow the prompts of the instructional team during lab. The schedule is given below:

Agenda: Time
1. Assembly Instructions, Roles, Responsibilities, Data Collection : 15
2. Trial Run, 1-2 finished pieces : 05
3. Run Cycle 1, Push : 10
4. Complete Scorecard, Reverse Cycle/Disassemble/Reinitialize : 10
5. Debrief, Data Analysis, Root Causes, Improvements, Group Discussion : 15
7. Run Cycle 2, Pull : 10
8. Complete Scorecard, Reverse Cycle/Disassemble/Reinitialize : 10
9. Discussion, Memo Notes, Dismiss : 05

TRAINING LEADER NOTES:

Stress time management and logistics, although schedule is full of slack

Stress pushing pre-lab prep and reading of procedure and role cards

Record student roles on sheet

Refer to slides, role cards, assembly instructions, setup/layout file, score card, data logs, assembly instructions, self-populating data spreadsheets

Can do a run with GTAs/Faculty for trial

Keep system primed, 1 for each part variety (excluding colored handles) results in 3 at each station

Do not mix up non-standardized parts (discs, body nuts/bonnets, bodies)

Potential remedies for cycle 1:

1. From 4 to 2 tables
2. Reduce space between operators (similar to above, but specifically to save motion, transport, not just real estate/equipment)
3. Remove operator(s)
4. Reverse flow to customer
5. Pull, kanban
6. Practice (training)
7. Uncover poor practices by some operators and correct by personnel movement or standardized training / retraining
8. Have whole line repeat customer order aloud
9. Add operators at bottlenecks
10. Move M300C-specific operations to beginning of line so that other product can proceed while M300C subassembly of compression fittings to body are prepared (a likely bottleneck)
11. Double-up/combine low cycle time operations, split up high cycle time/bottleneck operations
12. Only keep certain stations primed (major operations or bottlenecks)

Roles and Responsibilities of Students

The number of participants in each lab section is 32-36 people. Students are broken into two different supplier manufacturing lines, #1, Inc. and #2.com, and the customer of each suppliers’ products. Below is the student mapping breakdown in order to start.

<table>
<thead>
<tr>
<th>#1, Inc.</th>
<th>#2.com</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operators</td>
<td>9</td>
</tr>
<tr>
<td>Operations Manager</td>
<td>1</td>
</tr>
<tr>
<td>Transporters</td>
<td>1-2</td>
</tr>
<tr>
<td>Quality Control</td>
<td>1</td>
</tr>
<tr>
<td>Timer/Analyst/IT/Data</td>
<td>2-3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>14-16</td>
</tr>
<tr>
<td>Customers</td>
<td>2</td>
</tr>
</tbody>
</table>

For an explanation of the responsibilities of roles, please see the slides or lab handouts. The defect guide sheet will be used by Quality Control and Customers. Customers, Quality Control, and Analyst/IT/Data Collectors all must collect data, some regarding order fulfillment, order timeliness, and others regarding quality.
Sequential Workflow Initial Layout

Improved Layout
#1 Inc. is shown for a possible 2nd run solution, with #2.com in the original layout for comparison. Operator 7 is optional. Students may determine that a layout with even fewer operators is manageable, however, the important thing is that they reduce stations/workforce by at least 2-3 (based on line leveling, looking at stations that are underutilized, not arbitrarily) to provide for a production system footprint that occupies only half the original space. Also, reorienting the sequence so the output end is closer to the customer helps eliminate waste due to motion and possibly the Transporter. Combining this or a similar approach, using the best operators and improved training (experience and consistency gained from the first run), in addition to Pull and Kanban discipline should result in a much improved production system, specifically higher quality (more on-time delivery, accurate orders, fewer defects) and increased productivity which should lead to lower costs and increased profits.

### Results Sheet Scorecard

<table>
<thead>
<tr>
<th>Metrics</th>
<th>Cost / Unit</th>
<th>Cycle</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overdue Orders</td>
<td>$110</td>
<td>6</td>
<td>500</td>
</tr>
<tr>
<td>Value Added Time (VAT)</td>
<td>see</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Operator 1</td>
<td>see</td>
<td>Time 2 or 1</td>
<td>Operator 2</td>
</tr>
<tr>
<td>% Value Add (VAT/LT)</td>
<td>%</td>
<td>% VALUE</td>
<td>% VALUE</td>
</tr>
<tr>
<td>Quality</td>
<td>Internal Defects</td>
<td>$165</td>
<td>0</td>
</tr>
<tr>
<td>External Defects</td>
<td>$100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Costs</td>
<td>Total</td>
<td>$100</td>
<td>0</td>
</tr>
<tr>
<td>Summary</td>
<td># Defect Free Deliverables</td>
<td>count</td>
<td>21</td>
</tr>
<tr>
<td>Revenue – Value</td>
<td>$2,100</td>
<td>$2,100</td>
<td>Customer</td>
</tr>
<tr>
<td>Time and Defect Free Deliverables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Profit – Revenue – Total Costs</td>
<td>$1,000</td>
<td>$1,000</td>
<td></td>
</tr>
<tr>
<td>% Defect Free Deliverables Received/Total # Deliverables Ordered</td>
<td>%</td>
<td>50%</td>
<td>10%</td>
</tr>
<tr>
<td>Quality Defect Breakdown</td>
<td>M300</td>
<td>%</td>
<td>0</td>
</tr>
<tr>
<td>M305</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M310</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M315</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M400</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M405</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M500</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>M505</td>
<td>%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>count</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Summary

- # Defect Free Deliverables: 21
- Revenue: $2,100
- Profit: $1,000
- % Defect Free Deliverables: 50%

### Quality and Productivity Improvement Notes (stations, duties, layout, space, employees, Cycle1 to Cycle2, etc.)

- Results Sheet Scorecard
- Quality and Productivity Improvement Notes
**Calculations/Definitions**

**Overdue Orders** = number of orders which were not received within 1 minute of ordering × $150

**Lead Time** = Amount of time it took from customer giving order, to the order being received by the Customer (during the run, mark a piece of tape on a raw material to track the total lead time)

**Value Added Time** = Using stop watches the time observers must calculate the total process time to assemble 1 deliverable for each Operator. Spreadsheet calculates average time. The sum of these averages is total value added time.

**% Value Add** = Value Added Time / Lead Time. This tells us how much of the total lead time is actually value added time. The remaining being non-value added.

**Internal Defects** = Total # of defective deliverables found internally × $50 per defect

**External Rejects** = Total # of rejected deliverables received by the customer × $100 per reject

**Raw Material** = Raw Materials sitting within operations. Each individual material will cost $2. Raw materials represents supplies which Operators have not begun to assemble. All materials (even those which are not used in assembling the deliverables are counted ie waste).

**WIP Inventory** = Each deliverable which is partly assembled by an Operator will cost $10.

**Final Goods Inventory** = Inventory sitting at the end of operations waiting to be transported to the customer, or waiting within QC will cost $20.

**Space** = # of tables utilized within the operations × $200 (ie stores, each Operator’s table & QC).

**People** = # of staff required within operators × $100 excluding Customers, and Observers.

**# of Defect Free Received** = # of defect free deliverables received by the customer

**Revenue** = Multiply number of Defect Free Deliverables Received by $100/ deliverable

**Total Costs** = Add all the costs listed above

**Average Cost per Deliverable** = Total Costs / # of Defect Free On Time Deliverables Received

**Profit/ Loss** = Revenue – Total Costs

**Customer Service %** = # deliverable orders which are on time / Total # of deliverables ordered by the Customer (60 in total).

**Quality Defect Breakdown** = total quality defect numbers identified by customer and quality control.
Scorecard Completion Requirements

- # Rejects and Defects – Ask from QC person and from Customer
- # Overdue orders – Ask from Customer
- # of Defect Free deliverables received – Ask from Customer
- WIP Inventory – Ask from Operators (They must count the # of deliverables that are partially assembled in front of them)
- Raw Material – Ask from Operators (They must count the # of pieces that have not been partially assembled, as well as all of the waste (materials they don’t use) that’s in front of them) **NOT USED, ONLY HYPOTHETICALLY IN DISCUSSION QUESTIONS**
- Final Goods Inventory - From last Operator and QC person (They must count the amount of completed deliverables)
- Lead Time – Timer (this is the time tracked with the piece of tape)

Review the scorecard. Determine initial opportunities to improve the business.