From Students to Consultants: Transforming Manufacturing through People and Processes

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1. Introduction

When teaching industrial engineering, professors introduce concepts like lean and the Toyota Production System (TPS) as technical frameworks to solve industrial problems. However, as professors also explain, technical skills represent only half of an industrial engineer's toolkit. Lean and TPS are as much technical frameworks as they are social frameworks that define a company's management and decision making. Yet class assignments, including case studies and exams, tend to focus on hard skills like identifying *muda*, improving quality, and designing plans for continuous improvement. Soft skills, which are essential to grow and maintain positive culture, see far less practice in the classroom.

Corporate internships are a way to overcome this weakness in the curriculum and more accurately represent a work environment. Unfortunately, internship experiences often fall short due to time limitations. Constrained to only a few weeks, internships often introduce a problem that can accompany any consultancy: major players are present, and then they are not. This issue is coupled with set beginning and end dates, which give the impression that once an internship ends, so does the work that internship motivated. As a result, many companies assign interns to individual kaizen projects instead of to long-term design or development. While this action resolves the problem of tight time constraints, it also produces a barrier that relegates interns to short-term, and often less important work. Interns miss out on making significant contributions, while liaison companies miss out on the full potential of their interns,

It may therefore appear that the time constraints of a summer, or even a semester, overwhelmingly limit the knowledge students can develop and the impact they can make through corporate internships. A project-based format is a necessary compromise to get students into work environments even if the scope and consequence of their work is reduced. This need not be the case. Even under tight time constraints, students can facilitate successful and lasting lean transformations given proper support. Designing opportunities that focus on individual development, multilevel communication, and project impact maximizes internship results for both interns and companies.

2. Riggs Fellowship for Engineering Management

The Riggs Fellowship is an industrial engineering and management summer research opportunity offered by Harvey Mudd College that exemplifies how students can produce significant value for liaison companies in short time frames. In 2019, the Fellowship team, comprised of four undergraduate engineers and an advising professor, developed and implemented continuous improvement objectives that resulted in total annual savings of more than $600,000 between two companies. Moreover, in 11 weeks the team completely redesigned and implemented a manufacturing line to increase throughput, decrease defects, and introduce a culture of continuous improvement. These successes are a result of an insistence on student empowerment, an emphasis on multilevel communication within management, and a focus on long term impactful work, that make the Riggs Fellowship distinct from other industrial internships.

2.1. Students

A key feature of the Riggs Fellowship is the extensive technical background students gain before their corporate experience and how this background empowers them to achieve excellent results. Students apply to the Fellowship in the fall semester before their summer experience. Most recipients are engineering majors in their sophomore or junior year who have already completed coursework in engineering systems, differential equations, linear algebra, and multiple engineering sciences. Additionally, every student completes semester-long machine shop training through an engineering design course. These courses make up the Harvey Mudd College engineering core curriculum. Since engineering students at Harvey Mudd College do not specialize in individual fields, they are able to take a wide breadth of courses which allows Riggs Fellows to approach manufacturing problems with multidisciplinary solutions.

In addition to the core curriculum, Riggs Fellows also must complete the technical elective Manufacturing, Planning, and Execution. This course provides a depth of knowledge in shop floor management, quality management, and supply chain management that is fundamental for approaching industrial engineering problems. Students gain a foundation in lean and six sigma with a focus on factory layout, optimization, and process improvement which they apply throughout the semester in a variety of case studies and projects. Students also learn to track and map value streams, design factory layouts, innovate on existing processes with statistical process control and design of experiments, and meet manufacturing goals. By summertime, Riggs Fellows possess the technical frameworks to solve industrial engineering problems. This fundamental understanding forms the basis for their work over the summer.

However, the training Fellows complete before their summer opportunity goes beyond extensive coursework. Fellows attend the IISE annual conference a few weeks before they begin their summer work in order to learn current industrial theory and technology. Conference attendance offers two major benefits to students that are difficult to achieve in the classroom. First, students can pursue their individual interests within the subfields of industrial and systems engineering by attending poster sessions and lectures. These forums offer students new ideas and helpful references to current literature that often sparks innovative ideas during the summer. Second, the conference presents an opportunity for students to interact with experts from both academic and corporate spheres. These interactions allow students to practice professional interpersonal communication and help students bridge the gap between academia and business.

Altogether, the combination of both broad and deep engineering coursework with conference experience grants Fellows significant background before they ever begin corporate work. As a result, unlike many interns, Riggs Fellows are able to not only learn through their summer internship but are able to teach. Riggs Fellows approach their assignments as consultants rather than internal employees. This distinction is fundamental, as it creates a space that both allows students to take risks with creative solutions and allows for liaison companies to fully leverage student capability.

2.2. Communication

Another key feature of the Riggs Fellowship is the amount of communication students maintain throughout multiple levels of the corporate management chain. The success of the Fellowship’s consultancy model relies on all levels of management to buy into proposed solutions. Therefore, students maintain and foster open lines of communication with their liaison company that usually fall into three general categories.

The first level includes individuals like factory owners, CEOs, and general managers. These stakeholders are significant because they have the power to make impactful decisions. However, they are often not involved with a line’s everyday operations management. The necessary buy-in these individuals must make for a lean transformation is large while the time they can afford to students is small. Therefore, Fellows focus on creating strategic points of interaction. The first point is at the beginning of each project, where members of this first level are the ones to give an initial tour and first introduction to staff. This establishes the team’s credibility and helps begin the process of building trust. Further interactions are usually scheduled through meetings to discuss significant milestones and complications. Communicating at this level helps to build concise presentation skills and proper meeting preparation.

The second level consists of engineers, production managers, and supervisors who are involved in directing everyday line operations. Riggs Fellows work with this group on a daily basis because these individuals are extremely important for the success of a lean transformation. As consultants, Riggs Fellows have a responsibility to not only convince members of this group of the power of a lean framework, but to teach them how to maintain and contribute to the framework themselves. This kind of teaching requires two forms of regular interaction. Formal meetings to share ideas and implementation steps provide a space to share manufacturing theory and discuss why designs may or may not be ‘lean.’ Less formal meetings on the production floor are useful for showing problems as they occur and demonstrating why and how a lean solution would work. Overall, it is not enough for members of this group to simply ‘buy in’ to lean. Riggs Fellows catalyze lean thinking while they are present, but it is the continuous work and improvement after the summer— by those at this level— that can be truly transformative.

The third level is made up of the line operators whose everyday jobs will be affected by any change that higher levels of management may implement. Interactions with this group are usually less formal but focused on building trust and confidence. In the first few days on *gemba* Riggs Fellows learn to address each operator by name an understand their day to day jobs. This helps to set a good first impression and allows for better characterization of the line operations. Fellows listen for small requests and areas of unhappiness, often related to quality of life, and demonstrate an inclination towards doing by addressing these concerns quickly. Furthermore, operators are important shareholders that have to buy into a lean framework as much as other levels of management. Before periods of fundamental change, such as floor redesign, Fellows are sure to meet with all operators to explain and demonstrate reasoning for changes and address any concerns. By placing the operator input first in design changes, Riggs Fellows are able to more easily manage change and demonstrate servant leadership to other managers.

2.3. Impact

Overall, the consultancy structure of the Riggs Fellowship allows Fellows to engage in a corporate environment while relieving pressures of corporate bureaucracy. As outsiders, the Riggs team has the ability to step back and view the manufacturing process in its entirety. With this viewpoint, the team can develop wide reaching improvement plans for an entire line. However, project development is only half of the Riggs Fellowship work. To make the greatest impact, Riggs Fellows follow through with their consultations by supporting the implementation phase and developing a culture that the operators and management can take ownership of— to continue reaping the benefits of lean for years to come.

Value stream mapping (VSM) is the integral first step that Riggs Fellows use to evaluate the current state and potential future state of a manufacturing line. To understand material and information flow, Riggs Fellows spend significant time in *gemba* observing and speaking with managers and operators. Fellows complete their own time studies and make observations to create a comprehensive map of the current manufacturing process, its strengths, and its shortcomings. It requires one to two weeks to complete a current state VSM. Attention to detail at this step is a foundation for future success. A well-crafted map reveals bottlenecks, areas of overproduction, and changeover inefficiencies that represent areas where change can be impactful.

After identifying regions of inefficiency, the team does not immediately begin tackling individual projects. Instead, Fellows spend another few weeks crafting a future state VSM that represents an improved line that is still within the constraints of operators and machines. Developing this map relies on implementing a takt time representative of customer demand and redesigning processes to meet this takt time and level the line. The future state VSM is an agenda setter, revealing specifically which processes need reimagining and quantitatively showing how big that change must be. Armed with this knowledge, Fellows can begin designing and implementing knowing that their solutions will be impactful.

Kaizen projects are one of the simplest tools to help achieve a future value stream. These projects represent limited scope point improvements that can make a large impact by overcoming bottlenecks. The Riggs team selects kaizen projects to specifically resolve shortcomings in the current state that must be resolved to successfully implement the future state This often entails simple acts like revising operating procedures or redesigning organization schemes in order to meet a metric like cycle time or changeover time.

One particularly useful tool Riggs Fellows have used to implement kaizen projects quickly is the modular Flexpipe build system. Flexpipe is a building material designed to embody the flexibility of the Toyota Production System. It consists of metal pipes, various connectors, and several accessories that can be fabricated with nothing more than a pipe cutter and Allen wrench. Moreover, supporting CAD libraries are as simple to use as making line drawings. The material allows Fellows to create custom workstations and appliances in several hours instead of several days and empowers operators to continue to make improvements even after Fellows leave. Overall, Riggs Fellows have found that introducing Flexpipe helps a line become more agile, empowers operators to control and improve their own workspace, and expedites successful kaizen events.

Often, implementing a future value stream requires changes that are greater than a single kaizen event. Developing FIFO lanes, converting to small batch or single piece flow, and parallelizing processes may be integral for meeting takt time, but require significant investment to move machines or redesign operations. Nonetheless, Riggs Fellowship teams have designed and implemented such larger-scale improvements within a single summer through successful communication, proper planning, and attention to technical details. The intricacies of this process are best captured by examining a Riggs Fellowship project from the summer of 2019.

3. Ametek Ameron

In the summer of 2019, the Riggs Fellowship helped to improve a manufacturing line at Ametek Ameron (Ametek), an aerospace supply company that provides both OEM and MRO services for several aviation-related product lines. The specific line, known as B/E, was a high-volume OEM department that produced multiple types of oxygen cylinders for a single buyer. Forecasters at Ametek expected the demand for this line to increase by 25% in the coming year. However, the line's current state was already operating at maximum capacity and relied heavily on overtime to complete orders. Managers at Ametek invited the Riggs Fellowship team with the goal of resolving this issue and increasing line capacity by 25%.

To reach the 25% improvement goal, the Riggs team broke the project into four major actions:

1. Understand the current state procedures and layout of the B/E line
2. Develop a future state design and corresponding plant layout based on lean principles
3. Implement the future state layout
4. Follow through with implementation and begin continuous improvement activities

3.1 Current State

Riggs Fellows used their first four weeks to gain a strong understanding of the current state of Ametek's production line. During this phase, the Fellows combined their analysis of Ametek's historical demand data with their own observations and time studies to complete the current state VSM in Figure 3.1. Completing this map allowed both the Fellows and the Ametek managers to better understand their current material and information flow, and isolate processes that contributed significantly to waste.

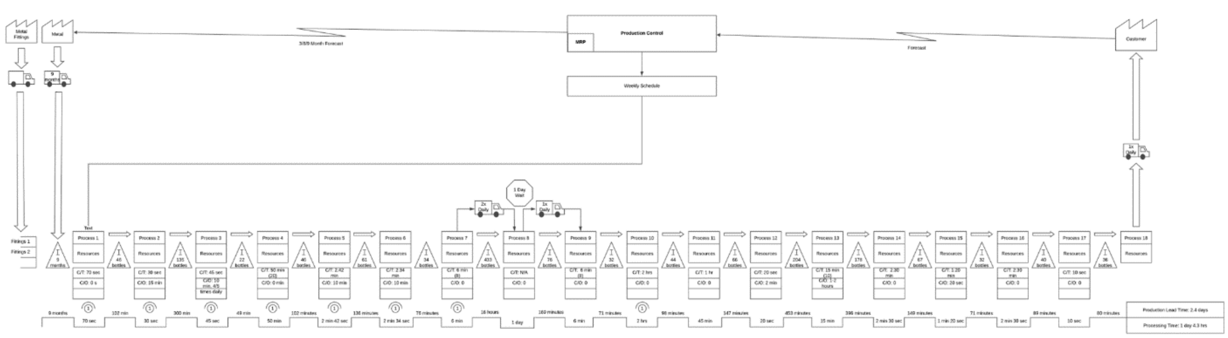


Figure 3.1: Current state VSM (June 2019)

While crafting the VSM, inventory and production values were inherently variable due to the line's push-based nature and the several types of oxygen cylinders. In order to capture a reliable snapshot of the line's operation over June 2019, Fellows used the following methods:

- Cycle times were averaged over several days from time studies covering multiple bottle types at randomized hours.
- Inventory values capture average total amounts for the line; material quantities varied significantly each day as work in process (WIP) pushed through the line.
- Lead time was estimated as the sum of value-added and non-value-added activities.

- Processing time represented the average sum of the value-added activities for each operation.

Table 3.1 shows the key metrics Fellows were able to determine while developing the VSM. These results characterize the B/E line's operation and represent areas that must improve in order increase daily capacity. In particular, 30% average overtime meant that Ametek effectively paid each operator for an additional 2.4 hours each day and still missed production goals by 13%. This amount of overtime was tied to the large amount of inventory that processes pushed through the line. Ultimately, both of these factors would strongly inform the team's efforts in evaluating the future state plan.

Table 3.1: Production metrics of the B/E line (June 2019)

% Overtime	30%
# of Operators	15
Daily Production Target	**198** bottles
Actual Production	**173** bottles
Lead Time	3.6 days

3.1.1 The Lean Perspective of the Current State

The VSM demonstrated that many of the B/E line's inefficiencies arose from a disconnectedness between individual processes. Imbalanced cycle times resulted in waves of WIP inventory that slowly moved through the line and accumulated after faster processes and before slower ones. Batching within processes further separated operations from each other. These wastes manifested themselves as:

- High WIP inventory between operations
- "Feast to Famine" operator uptime where operators may have little work for several hours and then receive a severe influx that required overtime to complete
- Job shop management where operators' work was delegated rather than standardized

Figure 3.2 shows some examples of inline WIP that highlight the systematic inventory problems on the line as of June 2019. From these observations, Riggs Fellows recognized that the future state line must connect processes with smaller batches and single piece flow, level cycle times, and standardize operations management.

Figure 3.2: Large amounts of WIP inventory at various points in the line

3.2 Future State Proposal

The first step in designing the future state was to develop a future state VSM to prove that changes could successfully result in 25% improved efficiency. The planning for this map focused on three major areas:

1. Performing line balancing to ensure individual operations function within takt time
2. Cellularizing operations into single piece flow and eliminating unnecessary buffer inventory
3. Reevaluating manufacturing procedures to remove non-value-added time

Figure 3.3 shows the future state VSM of the line that Riggs Fellows used to inform their future state proposal.

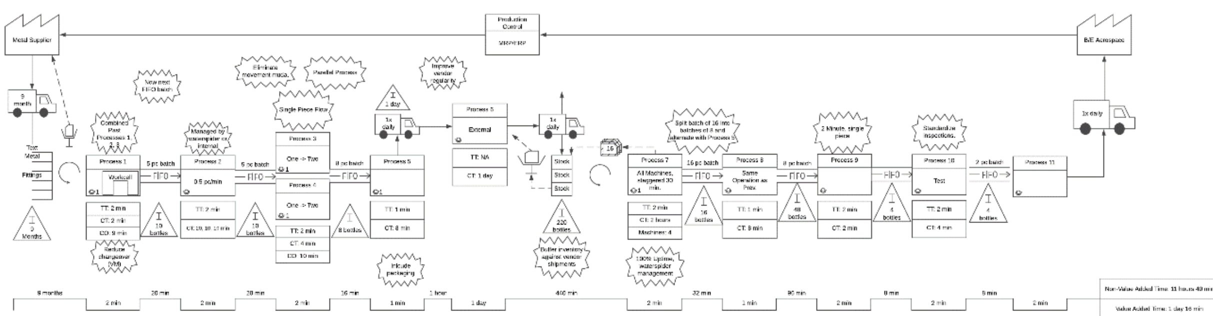


Figure 3.3: Proposed future state VSM

An important factor when designing the future state value stream was the customer demand, or takt time, required for this line. This time represents how often the production line must produce one cylinder in order to meet the daily demand. Fellows used the past twelve months of orders plus an increase of 25% to determine necessary daily production. Dividing 450 minutes, the average time in a workday, by daily production yielded takt time in minutes per bottle. The takt time then dictated the amount of time around which each individual operation had to be balanced.

3.3 Future State Implementation

The implementation and improvement stages occurred during the last six weeks of the Fellowship. During implementation, Fellows proposed their future value stream, provided plans to meet this value stream, and oversaw change management to successfully complete the lean transition. Overall, implementation had to overcome two major classes of challenges: engineering and management. Management hurdles included implementation of new roles and operating procedures while engineering challenges concerned issues like batch size and material flow changes.

3.3.1 Introducing Changes

A significant part of implementation was the communication and change management required by the Fellows to ensure a successful transition. For Ametek, this communication occurred through three major lines: daily communication with the line manager and production supervisor, a mid-summer meeting with all department managers to address changes, and training meetings to prepare operators.

From the onset of the Fellowship, Fellows worked with the line manager and production supervisor to design new operating procedures and layouts. This line of communication allowed Fellows to introduce these key players to lean and six sigma problem solving methods while also including their input for the final plans. Including these managers with daily design iterations helped to build their trust in the Fellows' reasoning and improve their confidence in proposed improvement plans. Building this trust was essential because changes like moving machines and altering material flow require long-term management and significant investment. In addition, these managers were expected to take ownership of changes after the summer and so their approval of the changes was a top priority. Once these managers had bought into changes and understood why they were necessary from a lean perspective, they served as key allies for convincing remaining stakeholders.

The mid-project meeting with department managers and the general manager was designed to further improve buy in to layout changes after they had already been confirmed. In the first part, the advising professor presented on a lean transformation he had overseen that saved a factory from shut down and eventually led to the dissolving of a union at the operators' request. After this, the Fellows introduced their proposed changes and the lean theory that guided their designs. This order helped to establish the ethos of the Fellows and allowed these managers to understand the power that thinking lean can have on improving a company.

Finally, the Fellows utilized two major formal meetings with operators in order to manage the immense changes that a lean implementation would have on their everyday roles. In the first meeting, the advising professor and the Fellows oversaw a lean simulation to help demonstrate the efficiency of production leveling, single piece flow, and refined layouts. This simulation used a hands-on model of a paper airplane factory that showed progressively better throughput and higher quality as batch sizes decreased, operation times leveled, and layouts compacted. Showing lean instead of lecturing about it allowed operators to easily understand why the Fellows were present and gave them the opportunity to share their own improvement ideas. Overall, including operators into the design process gave them stronger buy in to change and resulted in less resistance during implementation.

To further this, the second meeting occurred on week five, right before movers were scheduled to kick off the transformation with a new layout. A key feature was planning the meeting as a celebration with food and drinks to help operators feel more at ease with the proposed changes. The meeting introduced new roles, such as water spider and team leader, that operators would fill and helped to clarify their new standardized work as opposed to previous job shop assignments. Additionally, the meeting showed CAD documentation of layout changes so operators could understand what their new floor would look like. Altogether, these meetings and demonstrations empowered both operators and managers at Ametek to take ownership over their lean transformation. By acting as catalysts for liaison companies to make their own changes, Riggs Fellows are able to make significant impact within tight time constraints.

3.3.2 Layout Changes

The original machine layout of the B/E line was the result of organic growth from an initial line that attempted to produce production cells without leveling cycling times. Due to cycle time imbalances and several years of changes to operation procedures, WIP would travel back and forth between multiple rooms and outside areas and accumulate between operations. The Riggs Fellows produced a rough spaghetti flow diagram to document WIP movement and provide insight towards regions that needed improvement.

One major improvement was combining the initial machining processes into a single cell. Initially, three operators would move inventory between two room two times to complete these operations. In the new layout, consecutive machines were moved into a single room and internal cycle time was leveraged to run the machines in parallel with a single operator. This instance utilized a U-shaped cell, which was elaborated on throughout the new layout. This removed all internal WIP, reduced WIP movement by 62%, and isolated dirty machining operations from the rest of the line.

Another significant layout change was combining two separate welding processes into a single parallel one. Parallelizing the processes into a single operation allowed it to meet takt time while leveraging operator wait time. In the time used originally to wait for a welding robot, operators could now set up another unit on a second machine. This significantly sped up an originally slow process and helped link it to the next process by small batches.

Layout changes also included several key features that assisted in the quality of the work environment and management capacity. Moving machines closer together removed carts and shelves that originally housed WIP. The extra space allowed Fellows to include uninfringed four-foot aisles that better facilitated material flow. This space also allowed the line engineer and supervisor to move their workspace onto the line, making them more accessible for operators. Finally, by removing barriers and high shelves, the new layout allowed for unobstructed vision across the shop floor that improved supervision.

Finally, the Fellows noticed that there were extraneous and disordered processes that contributed to WIP movement. One example was the movement of bottles from quality assurance (QA), to a machine, and back to QA, sometimes more than once. Another extraneous operation chain resulted in a need for cylinders to undergo a drying operation two times even though it was only necessary once. Reordering and removing extraneous operations reduced WIP wait time by twenty minutes per bottle and reduced WIP movement by nearly 33%.

3.3.3 New Operator Roles

In order to establish the future state, an additional role had to be introduced to the B/E line – the material handler. The material handler’s main role is to supply station operators with material and tools so that they never have to leave their respective work areas. The addition of a material handler greatly increased the efficiency and concentration of operators, who no longer had to search for material.

Another role that the Riggs Fellows introduced was the team leader. In the original iteration of the B/E line, a senior operator would oversee many of the machine related problems that would arise each day. However, due to the job-shop nature of the line, this operator was often relegated to machining and assignment tasks instead of aiding to develop improvement or maintenance strategies. This was largely due to tacking the leadership role onto existing line operator responsibilities. In the new layout, a team leader filled a high-level operations role with the task to help combat operational problems as they occurred. For example, the team leader helped to resolve material influxes or fill in for others if they needed to use the restroom.

Moreover, the team leader served a vital link between mangers and other operators, enforcing an Andon light system to signal problems as they occurred. Overall, the team leader role allowed operators to overcome everyday production challenges with little higher management intervention. This frees higher management from everyday firefighting and allows them to focus on implementing continuous improvements.

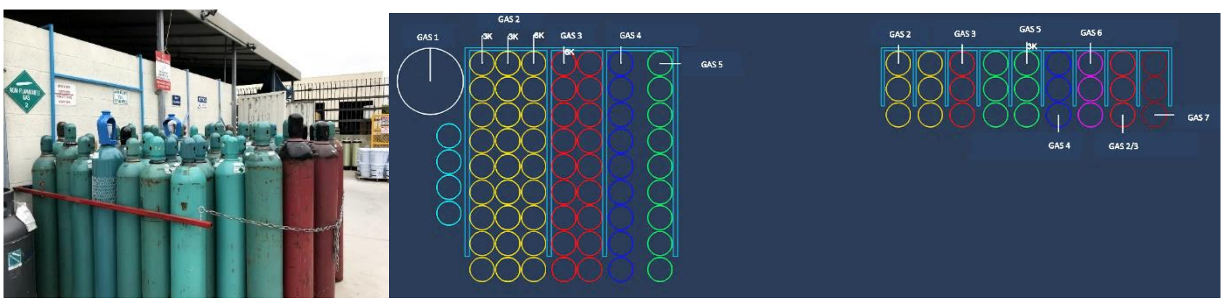
Selecting operators for new roles was a difficult challenge that the Riggs team left primarily to Ametek management. However, Fellows provided recommendations to select operators for new roles who previously held roles with similar purpose. Extra meetings were scheduled with these operators in order to stress the importance of their work and how in the new lean system their successes would allow for the entire line to succeed. After the layout change, Fellows spent several weeks shadowing these operators to help them learn and better accomplish their new position.

3.4 Future State Continuous Improvement

After week six, movers successfully completed implementing the future state layout and operations resumed according to the Fellowship's initial plans. However, the Riggs Fellows needed to stress to Ametek management how successful manufacturing lines cannot become complacent in their own improvement. Instead of watching the improved line and letting it settle, Fellows immediately began improvement projects to foster a culture of continuous improvement. Over the final weeks, Fellows completed a variety of kaizen event projects to further build on the new flow and operation platform the new layout provided. The following sections highlight some of these projects.

3.4.1 Organizational Improvements

For the purpose of reducing changeover times, decreasing hassle, and increasing safety across different low-priority tasks, the Riggs team reimagined the organization of a few of these areas. These changes displayed the importance of continuous improvement and executing tasks that otherwise get overlooked, especially when management is accustomed to firefighting on the production line rather than identifying root-causes. In Figures 3.4 and 3.5, before and after images show how a small time investment can lead to savings in many different ways.



(a) (b)

Figure 3.4: Gas cylinders before organization (a) and the implemented plan for future organization (b)

A readily observable problem was the amount of time operators spent retrieving and inventorying cylinders of compressed gas. Ametek kept gases for various lines in a single outside storage location known as the 'farm.' During time studies, the Riggs Fellowship team witnessed operators spending more than 30 minutes counting and finding bottles.

The team determined that the root cause of this problem was twofold. First, the gas cylinder farm was disorganized, making any handling or management procedure difficult. Second, the gas cylinder supplier had no standardized drop off location of specific gasses. To solve these problems, the Riggs Team implemented a simple visual management system.

This system helped solve both problems. Standardized gas locations eliminated any need to find specific gasses and decreased searching and counting time to less than 3 minutes. Visual signs and dividers clearly indicated the proper drop off location to the supplier who helps to maintain the organization. Finally, organization allowed management to more clearly know the current supply and appropriately plan purchasing for the future.

For future improvements, management must work with the supplier to ensure on time delivery and a procedure to place excess gas in the case of an overorder. Overall, management must exert effort to maintain organization over these materials. As such, the mindset should be that organization is kept and tracked for the sake of easy management in the future.

(a) (b)

Figure 3.5: Old die storage (a) and new modified die storage (b)

Another kaizen project was to reduce the changeover time of the hydraulic press machine to less than 10 minutes. This particular changeover shuts down the entire machining cell. Minimizing changeover time would therefore minimize downtime. The 10-minute goal coupled with the lower than takt cycle time would limit changeover such that the machining cell could still catch up lost production.

During time studies, it was found that the changeover process for the press could easily exceed 20 minutes. The main reason for this delay was the disorganized die racks. As pictured in Figure 3.5a, the various sized dies are kept upright. While there was initially an attempt to organize dies by size, failure to maintain the organization lead to many misplaced or missing dies. Operators would spend many minutes searching for the specific dies they needed for a changeover.

Figure 3.5b shows the improvements that the team made. First, extra material and pieces from the cutting machine have been moved to another rack. The racks have been brought closer together and centered around a neutral lifting height. Heavier dies are stored at more ergonomic heights while the lighter pieces are either higher or lower. Next, pieces with identical diameters are stored together and have been color coded with tape to enforce this organization. Finally, the dies have been stored sideways and only at the front of the rack, offering an easier interface to safely access and pick up dies.

3.4.2 Innovative Technical Improvements

Over the course of implementing the future value stream with the new layout, several problems arose that required greater technical skills than simply organization. Fellows were able to address these technical problems by leveraging their broad engineering education. Although Fellows encountered a variety of technical problems that affected line operation, they focused on resolving those that most greatly undermined implementing the intended small batches and single piece flow. Three greatly impactful improvements include:

1. Designing a station to expedite cooling of bottles after welding, reducing wait time and inventory between two major processes
2. Transforming a large batch method for stainless steel passivation into a first-in-first-out (FIFO) lane

3. Cellularizing three machining operations by redesigning the processes for single piece flow and physically moving the machines to be in close proximity of one another

The layout changes that the Riggs team implemented revealed many opportunities for innovation. Rather than using bulky carts and 200-pound tables, the team could rapidly develop solutions to the material handling and basic tasks that the operators had to perform.

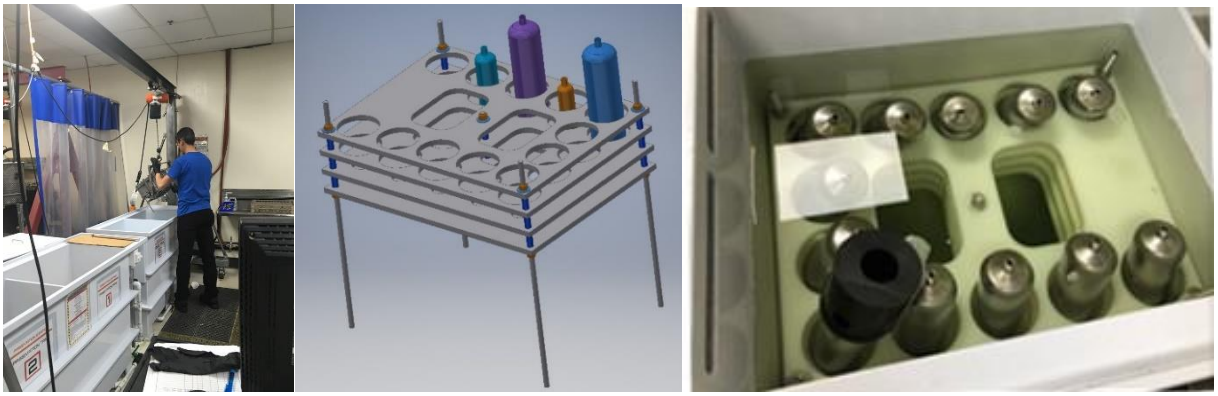
One issue with handling bottles came right after the welding process. Bottles often left the welding station at over 400°C, a temperature more than enough to cause serious burns if handled improperly. In order to use them at the next station, a cooling process was required. Figure 3.6a shows the old way of cooling bottles post-welding. This setup exemplified the batching mindset. Full baskets were lofted above shoulder-height and WIP piled the shelves rendering airflow limited and cooling inefficient. It would take upwards of 20 minutes for a bottle to be cooled to an acceptable handling temperature.

To improve this process, Riggs Fellows designed an easily accessible cooling tower with direct airflow that ran through the metal basket's mesh bottom for faster cooling as shown in Figure3.6b. The design of the cooler restrained the space to keep WIP down to minimum, reducing over 60 bottles to eight or fewer. It was then constructed out of Flexpipe. Flexpipe was perfect for the new implementation as it stays modular and could lend itself to a highly custom design. Due to the modularity of Flexpipe, operators were able to instantly seize more functionality out of the design by outfitting a basket underneath to store defects.

(a) (b)

Figure 3.6: Bottle cooling setup before (a) and new Flexpipe bottle cooler with two kanban stations (b)

Another operational issue preventing single piece flow throughout the manufacturing line was a batch passivation operation. This operation initially required a batch of 14 to 48 bottles to be submerged in a bath of citric acid for 45 minutes. In order to be able to submerge all bottles at once, operators would spend a significant amount of time securing bottles within a mesh crate, taking care to not damage the fittings. The long setup time coupled with large batch size and a long cycle time greatly hindered the line's agility and contributed to imbalances in WIP. Moreover, 14 to 48 bottles filled with citric acid is capable of weighing over 80 pounds and thus ergonomically unsafe to lift. This required operators to use a winch system as shown in Figure 3.7a.



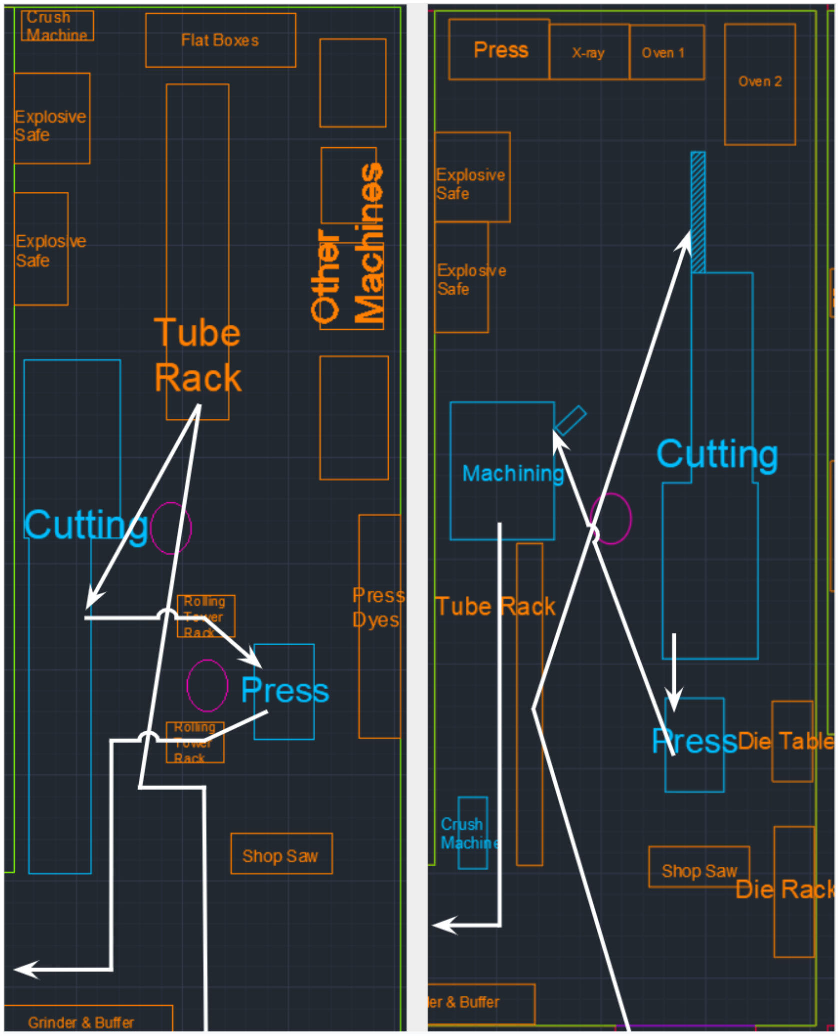
(a) (b) (c)

Figure 3.7: Original batch passivation with hoist setup (a) CAD of newly designed passivation tank layers showing bottle fit (b) and newly implemented system at work (c)

To improve this process, the Fellows invented a device to separate cylinders as shown in Figure 3.7b and Figure 3.7c. The purpose of this passivation device was to facilitate a FIFO lane within the citric acid baths. Careful arrangement of stacked HDPE sheets cut with concentric circles allowed the device to accept bottles of all lengths and diameters. Instead of moving a full batch, operators inserted a single bottle into each of the 24 available spaces every two minutes. Once all spots were filled, operators continued moving around in a circle, replacing the oldest bottle with a new one. A black HDPE ring marked the most recently inserted bottle, allowing operators to keep track.

This system replaced the 45-minute passivation wait time with a single piece FIFO lane that had an output one bottle per takt time. Moreover, the system could remain primed with bottles overnight, eliminating any setup time after first initialization. Implementing this invention coupled passivation with faster processes after it. Overall, this new design reduced WIP directly before and after the process from 100 to 12 and completely eliminated set up time.

A third major technical improvement that Fellows designed and implemented was an operating procedure for initial machining that introduced single piece flow. Figure 3.8 shows the before and after layout changes that made these operating procedures possible.



(a) (b)

Figure 3.8: Initial (a) and improved (b) machining cell layout

In the initial procedure, three operators used an autonomous tube cutter, press, and lathe to complete a bottle's body. Each operator worked independently and used WIP of up to 100 bottles between each process to buffer against cycle time differences. This WIP also helped to compensate for the large distance between the press and the lathe, which were located in different rooms.

The redesigned operation procedure allowed a single operator to complete all three tasks and keep up with takt time. All machines were moved into a single room, with control panels in close proximity to each other, to allow for safe operation with operator movement of less than 10 feet. The new operating procedure leveraged the autonomous settings on the tube cutter and lathe. A single operator would start a machine and move on to the next process while the first was still running. Doing this with all three machines allowed for a single operator to oversee their simultaneous operation while meeting takt.

The impact of internalizing operating time with cycle time was manifold. First, two operators were no longer required to complete the tube, allowing Ametek to dedicate them to other operations. Second, in-line WIP, which often totaled more than 300 bottles, was reduced to eight with a production buffer of 150 to allow for changeover. Third, throughput increased to meet takt time while considering changeover. Fourth, decreased handling helped to reduce the defect rate by 20%. Altogether, successfully implementing a lean production line requires many forms of innovative process improvements. These changes to machining along with the other technical improvements made it possible to run small batches and single piece flow throughout the production line and inspire a culture of continuous improvement to fully realize a future value stream.

3.4.3 Takt Time Production Counter

An important step in controlling and managing production is understanding when problems arise in real time. Tracking production with end-of-day totals is inefficient because it offers no opportunity for correcting errors during the production day. To help address this problem, the Riggs Fellowship team introduced production timers to the B/E line. These timers pictured in Figure 3.9 monitor actual production against a set goal that increments in accordance to takt time.

Figure 3.9: Installed production timer

Fellows installed production timers focusing on visibility, both in space and in information. Physically, operators and managers could observe the timers from any point along the production line. By making goal information transparent, both operators and mangers could clearly identify their performance at any instant. For both parties, this was empowering. The timers served as a management tool to help kickstart an ideal of rapid problem solving. Instead of waiting until end-of-day to assess production metrics, as had been in the norm previously, managers and operators now instantly knew when a production obstacle occurred and now had time to fix it.

3.4.4 Andon Lights

To further instill a company culture of continuous improvement and communication, the team put together an Andon light for each station. Figure 3.10 shows several Andon lights in construction that were later installed at each station. These lights are wired to a four-button remote that switch between each of the lights. A buzzer can also accompany the red light to alert the lead or supervisor if they are not within eyesight. As such, the red light indicates that the operator at a station has raised a problem, the yellow light indicates that the problem is currently being addressed, and the green light indicates that the station is operating as usual.

Though this hardware is relatively straightforward in its design and implementation, these lights represent something much bigger – a concept called “servant leadership”. In this leadership style, it is management’s job to listen to their employees and serve to improve their lives and jobs. By creating a channel of communication for employees to raise problems and issues with the line, the operators can provide effective feedback for the line and easily convey these problems to leadership. Then, the managers’ time will be spent solving problems that are directly hurting the line. Therefore, these lights should be seen as the start of a new paradigm at Ametek, one that focuses on directly addressing issues and emphasizing communication.

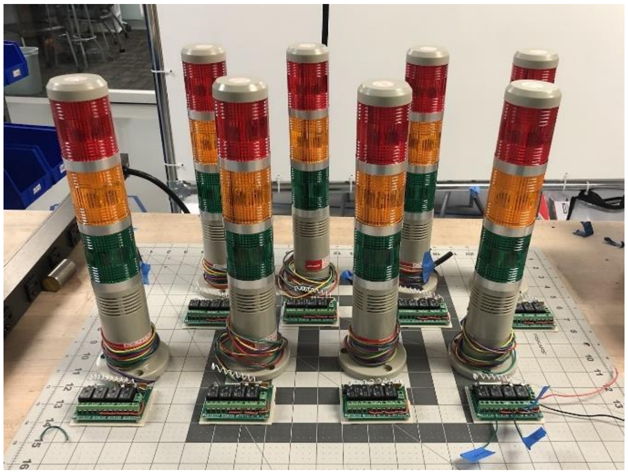


Figure 3.10: Andon lights after wiring

4. Results

Over the course of 11 weeks, Riggs Fellows helped start what would become a culture of continuous improvement. Leveraging communication and action helped the Fellows achieve lasting impact for Ametek.

Tangible results were tabulated at the end of the fellowship. Measurements found there to be a 27% increase in production despite a 20% decrease in the number of operators on the line and a 66% reduction in overtime. The amount of inventory on the line was also reduced by 62%. Giants carts piled with inventory were replaced with small Kanban stations with room for up to 5 bottles at a time, equaling an inventory reduction of over $100,000. Cost of quality on the line also went down by 25% due to there being fewer quality issues and thus fewer rejected bottles. Finally, there was also a measured 58% reduction in lead time. Altogether, the tangible impacts amounted to nearly $400,000 in annual savings. These tangible metrics can be observed in Table 4.1.

Table 4.1: Tangible metrics and annual savings

Metric	Initial Value	Final Value	Impact	Annual Savings
Daily Production	173 bottles	220 bottles	27% increase	N/A
# of Operators	15	12	20% reduction	$124,800
% Overtime	30%	10%	66% reduction	$205,920
Cost of Quality	$20,000 / month	$15,000 / month	25% reduction	$60,000
WIP Inventory	1,350 bottles	515 bottles	62% reduction	N/A
Lead Time	3.6 days	1.5 days	58% reduction	N/A
Total Annual Savings	-	-	-	**$390,720**

The completed work also entails several intangible benefits to the success of the B/E line. For example, signal-based resupply of material and problem raising will help improve the line's overall efficiency and eliminate the need for operators to find management. Decreased inventory will also help raise the most prominent issues that can shut the line down and will hold management problem solvers more accountable. Finally, standardized work, inventory, and material flow will improve operational excellence and help managers more clearly see problems as they monitor the line.

5. Conclusion

The 11-week Riggs Fellowship exemplifies how students can make large impacts at corporations by bridging technical and personal relationships. The unique nature of the Riggs Fellowship allows students to approach companies as experts in consultancy rather than interns looking for a summer position. As a result, the work done by Riggs Fellows is inherently expected by both the students and the company to have a lasting impact. This also means that the Riggs Fellowship requires commitment and trust on both ends to allow for multilevel communication and cooperation. For this to work, selected students must be strong communicators and have a deep background that brings together many engineering disciplines. In addition to applying classic industrial methodologies such as lean, 5S, and cellular manufacturing, Riggs Fellows can leverage their broad engineering background to make innovative and significant process improvements. By bringing together both technical and interpersonal expertise, it is possible for students over a single summer to have a profound and lasting impact that can transform manufacturing within a facility.