Analysis and Application of the Toyota Production System in American Manufacturing

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Abstract

The focus of this research is to explore the management practices characteristic of lean organizations with an emphasis on manufacturing applications. The history surrounding the development of the Toyota Production System (TPS) and *kaizen* culture, of which contemporary lean methodologies bear their foundation, will be examined through the insights of the manufacturing system's principal originator, Taiichi Ohno. The fundamental management techniques underlying lean philosophies, including but not limited to just-in-time production (JIT), the identification and elimination of waste, or *muda*, in operational processes, and the role of the *gemba* in managerial decision making will be investigated to ascertain how organizations adopting a *kaizen* strategy can realize the remunerations of higher quality, lower cost, and minimized delivery schedules in their respective production systems (Imai, 2012). Case studies related to the implementation of lean methodologies at American automotive manufacturing organizations will be studied to provide a quantitative analysis of the operational impacts of lean systems as well as the challenges faced by such firms in aligning organizational cultures to the *kaizen* mentality. In an effort to develop synergies between literary research and practical application, a twelve-week lean workout managed by the author for a Michigan-based, CNC manufacturing firm will be debriefed to serve as a praxis of the aforementioned themes; core areas of focus will include the challenges faced by the organization related to its existing operational condition, the value stream analysis of its production system, the objectives of the *kaizen* team, and the implementation plan of the team's recommendations for improvement.

Keywords: lean, Toyota Production System, *kaizen*, continuous improvement, manufacturing, *gemba*, NUMMI, Fitzpatrick Manufacturing Company, value stream

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Whether referenced in contemporary literature as six sigma, lean manufacturing, or continuous quality improvement, the underlying school of thought propelling such business philosophies concentrated on optimizing operational efficiency and customer value through the total elimination of waste in production processes bear their foundation in the Toyota Production System ("What is lean," 2018). Originally conceived by Taiichi Ohno (1912 – 1990) of the Toyota Motor Company in the 1930s as a competitive strategy to contend against the mass production model proliferated by Henry Ford, lean production methods have extended far beyond the parameters of the manufacturing industry, witnessing adaptions in the healthcare, financial, insurance, and customer service domains (Hanna, 2007). Arguably the leading consulting organization in lean strategies both domestically and abroad, the *Kaizen* Institute, founded by Masaaki Imai (1930 – present) in 1985, has partnered with multinational organizations across fifty countries to educate business leaders on the systematic, continuous improvement approach (Imai, 2012).

Taken from Japanese semantics, *kaizen,* a fundamental pillar of lean management systems, translates to "continuous improvement" and by its very nature implies a sharp disparity between Japanese and Western management techniques (Imai, 2012). Whereas Western methodologies "worship" technological breakthroughs and groundbreaking innovation that transform the business landscape, a *kaizen* mentality advocates subtle, incremental, and diurnal changes that "bring about dramatic results over time" (Imai, 2012, p. 2). Contentment with existing operational processes holds little value in a proactive, lean firm and instead imbues psychological stagnation on behalf of organizational leaders. However, such a temperament must not exist in isolation, sanctioned solely to the manufacturing line where fallacious perceptions of scientific management rigidly dictate human behavior according to unyielding standards, but rather, must permeate the institution from a bottom-up initiative of transformational development. To create a benchmark characterization of the *kaizen* methodology, Doman (2012) defines lean management as a holistic approach to business administration "in which problems are quickly identified and then solved by motivated employees who are trained to eliminate waste in their processes so that customers receive the highest quality products and/or services at the lowest cost in the shortest lead time."

Advent of the Toyota Production System

The Toyota Motor Corporation was founded in 1937 by Kiichiro Toyoda (1894 – 1952) and has since "become one of the preeminent global corporations of the 21st century," earning a net revenue of $247.7 billion in the 2017 fiscal year ("Toyota Motor Corporation," 2018b). The company's chief competitors include Volkswagen AG, General Motors Company, Ford Motor Company, and Honda Motor Company Limited, and the respective net revenues of its competitors for the 2017 fiscal year are $228.6 billion, $166.4 billion, $151.8 billion and $125.6 billion ("Toyota Motor Corporation," 2018a).

Initially operating under the name, Toyoda Motor Company Limited, up until the conclusion of World War II, inspiration to enter the automobile manufacturing industry was garnered under the leadership of Sakichi Toyoda (1867 – 1930), father of Kiichiro Toyoda. Envisioning diversification from the family business, Toyoda Spinning and Weaving, a textile loom manufacturing company, Sakichi toured the American Ford assembly plants in 1910 to study the revolutionary production of the Model T, which, at that time had been on the market for two years (Ohno, 1988). An innovator and nationalist in his own right, Sakichi foresaw the semblance of parallel production methodologies between the loom manufacturing industry and the automobile assembly line as well as a considerable market void in the small-scale production of diverse automobile models in Japan; upon returning from his excursion, he declared, “from now on, it’s the automobile” (Ohno, 1988, p. 88).

Autonomation

Sakichi’s chief accomplishment at Toyoda Spinning and Weaving was the invention of the auto-activated loom, a machine that encompassed twenty-five years of developmental research before completion in 1926 (Ohno, 1988). Embodied in such patented technology, which was later sold in 1930 for ￥1 million to support automobile research, the principle of autonomation was spawned and became the first of two core underpinnings regulating the Toyota Production System. Autonomation, frequently referenced as “automation with a human touch”, is the ability of a machine to detect abnormal production conditions and cease manufacturing to circumvent generating defects (Ohno, 1988, p. 6). Defects in the manufacturing industry “include waste such as scrap parts, products that require rework, or assemblies that are missing details” (Gay, 2016). Applied to textiles, the auto-activated loom diminished costs associated with manufacturing defects by automatically ceasing operation if either the vertical or lateral threads broke in the midst of a production cycle (Boakye-Adjei, Thamma, & Kirby, 2015). However, transitioning to automobile manufacturing, for example, in the event a die shears during the engine stamping procedure, a machine equipped with autonomation will recognize the irregularity, halt the work process, and notify the division operator through an *andon*, which is a visual control mechanism that flashes a red light when a system failure occurs. Fundamentally, autonomation entails a work stoppage for the entire production line when a single machine failure occurs, which is particularly taxing for mass production factories governed by limited time constraints. Understood in relation to the Maxcy-Silberston curve, the hazard of production barriers can be perceived from a financial outlook as mass production costs diminish “in proportion to the increase in quantities produced,” provided a limiting upper threshold with respect to the cost reduction capabilities (Ohno, 1988, p. 2). However, analyzed from the long-term perspective of continuous improvement, “stopping the machine when there is trouble forces awareness on everyone. When the problem is clearly understood, improvement is possible” (Ohno, 1988, p. 7).

Because the underlying objective of the Toyota Production System is the total elimination of waste, or *muda*, autonomation minimizes manufacturing costs associated with defective products (Ohno, 1988). Labor hours allocated to expensive re-work initiatives, expenditures associated with forgone material, the opportunity costs of subverted production, and potential liabilities accompanying defective automobile systems are elements of organizational risk that can be controlled through autonomation. Furthermore, autonomation breeds expansions in production efficiency by allocating human capital across multiple domains of the manufacturing process. Machines functioning in the absence of autonomation require direct supervision by a human operator trained to detect production abnormalities. Within a unionized engine assembly plant with, for example, one hundred distinct machines, one hundred machine operators will be required on each shift to maintain production schedules. The value added by the machine operator may be understood as his/her ability to subvert failures during manufacturing through in-process maintenance of production equipment. However, the effective adaptation of autonomation permits an operator to manage multiple machines in a common work cell because his/her attentiveness is not required during normal production conditions. Improvements in work cell layouts, production equipment, and the interdisciplinary training of the workforce drive the lean focus on eliminating a system fixated on an invariable number of workers (Ohno, 1988). Furthermore, labor costs are reduced as the ratio of machine operators to machines is minimized in comparison to Western counterparts; according to Hays (2012), Toyota requires 2.73 workers to produce one vehicle in its United States factories, whereas Ford, General Motors, and Chrysler necessitate 2.97, 3.04, and 3.20 employees, respectively.

From an implementation perspective in American industry, by-products of autonomation, such as one worker being able to manage multiple production functions, present unique challenges for managerial-union relations (Ohno, 1988). Collective bargaining agreements in the traditional Western automotive industry are characterized by multiple job classifications organized according to specific functions, such as lathe operator, tool maker, electrician, or welder. Working out of classification is perceived as a threat to employment stability and often accompanied by embittered grievances. Conversely, “in the Japanese system, an operator has a broad spectrum of skills. He can operate a lathe, handle a drilling machine, and also run a milling machine… operators acquire a broad spectrum of production skills … and participate in building up a total system in the production plant” (Ohno, 1988, p. 14). During periods of high activity, such workforce adaptability allows the production staff to allocate resources to procure swift resolution to complex system failures as well as increase employment security.

Just-In-Time Manufacturing

In conjunction with autonomation, the second pillar of the Toyota Production System is just-in-time manufacturing, which “means that, in a process flow, the right parts needed in assembly reach the assembly line at the time they are needed and only in the amount needed” (Ohno, 1988, p. 4). Just-in-time production was conceptualized by Ohno (1988) in the early 1950s after an excursion to General Motors and Ford assembly plants located in the United States. However, rather than marveling at the automotive push production lines, Ohno studied the efficiency of U.S. supermarkets and their distinct ability to provide a customer with the exact product of interest at the time and quantity necessitated. Keeping this system at the forefront of his mind, Ohno envisioned a cultural shift at Toyota in which each manufacturing division aligned its focus on providing the precise products and/or information to the downstream process. Rather than concentrating on fabricating the maximum quantity of components per shift, each production division would only produce the quantity demanded by the downstream process, which was ultimately determined by the production-leveled, sales volumes received by the assembly plants. The enactment of a just-in-time strategy implicates an atypical, yet logical, psychological transition from producing as much as practical to manufacturing according to the consumer's requirements (Ohno, 1988).

The precision of real-time information systems incorporated into the manufacturing line to transmit production agendas becomes paramount to the success of the just-in-time methodology. Initially introduced in the machine shops of Toyota in 1953 before later being implemented company-wide in 1962, the *kanban* system is the framework responsible for transmitting work orders to sustain a just-in-time strategy (Ohno, 1988). *Kanbans* are brightly colored and highly visual slips of paper attached to work-in-process that provide information to the work team regarding the production quantity, delivery schedule, method of manufacturing, downstream destination, storage point, and transfer equipment; see Figure 1 in the Appendix for an example of a *kanban* implemented in the Toyota Production System. The principle advantage of the *kanban* system is the reduction of inventory during the manufacturing cycle that results from overproduction. From the lean perspective, work-in-process and finished goods inventories do not add value to an organization, but rather, detract from the business's limited capital resources; "they add to the cost of operations by occupying space and requiring additional equipment and facilities such as warehouses, forklifts, and computerized conveyor systems. In addition, a warehouse requires additional personnel for operation and administration" (Imai, 2012, p. 82). The hesitation of Western manufacturing firms to liberate themselves from large-scale inventories can be juxtaposed with the volatility of the consumer market. Work-in-process and finished goods inventories create a comprehensive safety net that allows the business to spontaneously respond to surges in customer demand during high growth periods (Doman, 2012). Furthermore, the planned mass production methodology indicative of the early Ford assembly plants is often implemented in manufacturing firms with extensive re-tooling and/or change-over times as a cost reduction measure. The American automobile industry of the 1950s was founded on producing large lot sizes of a single part, which resulted in immense inventory levels and minimal diversification in product lines (Ohno, 1988). The Toyota Production System embodied the antithesis of this approach, preferring to produce small lot sizes of diverse automobile models required by the Japanese consumer market on assembly systems that championed marginal setup sequences; where setup schedules may have taken one hour in their Western counterparts, Toyota was able to attain a comparative time of fifteen minutes.

Ohno (1988) likens the strong psychological resistance to just-in-time manufacturing to the mentalities adopted by ancestral farming societies whose livelihoods were dependent upon the cultivation and storage of excess crop yields to mitigate risks associated with natural disasters. However, in the era of globalized markets and advanced computerized information systems, such a mentality is archaic. Organizational adaptability and the efficiency of change management procedures are becoming increasingly characteristic of viable organizations in modern industry; the wastes of overproduction and inventory management represent overhead costs that diminish margins and market competitiveness. However, organizational process change toward just-in-time manufacturing methods need not occur suddenly. Company leaders can effectively “manage the risk by planning and executing a gradual reduction in inventories as … processes are improved and become more reliable" (Doman 2012).

Spear and Bowen (1999) testify that the world-renowned success of the Toyota Production System, measured in terms of quality control, cost management, and delivery timelines, can be attributed to rigid rules and standardized instructions specifying the content, sequence, timing, and outcome of each production task; in a paradoxically manner, it is through disciplined adherence to operational standards that "flexibility and creativity are possible" (Spear & Bowen, 1999). The *kanban* system operates according to a strict arrangement of six principles in which employees are trained and continuously reinforced. Firstly, *kanban* is the demand signal that provides authorization to begin work; without a *kanban*, production will not commence (Feld, 2001). Such is the reason the Toyota Production System retains flexibility to compensate between periods of high and low growth in sales volume; fine adjustments in the production level are handled spontaneously because efforts to satisfy the customer's order are not undertaken until the *kanban* is processed on the assembly line. In fact, the second *kanban* principle holds that "no job is to be released without demand from the customer" (Feld, 2001, p. 54). In an idealistic, lean manufacturing plant, a *kanban* embodies the authentic demand of the customer, unadulterated by managerial agendas to maintain predetermined thresholds of final goods inventory which exemplify wastes of overproduction. *Kanbans* dictate the level of work-in-process permissible in the production chain while also determining the manufacturing lead time by means of a production queue; "queues are unable to grow beyond the number of calculated *kanbans*" (Feld, 2001, p. 54). Because the *kanban* system creates an internal customer-supplier-based network of excellence where the next customer is the downstream process, great emphasis is placed on the eradication of defects, or *gembutsu*. In the event the manufacturing line is halted due to an abnormality, *kaizen* behavior prescribes the immediate analysis of the *gembutsu* for problem identification (Imai, 2012). To avoid line stoppage for a prolonged period of time, temporary countermeasures are arranged before a comprehensive, cross-functional investigation of the root cause is conducted, typically commencing the following morning. Standardization of work instructions, total quality maintenance schedules, or operating protocols are proactive strategies to circumvent the reoccurrence of the preliminary problem. Continuing with the *kanban* principles, material and work order processing abides by the first-in/first-out (FIFO) imperative, the sixth axiom of *kanban* management (Feld, 2001). Under FIFO, each work cell must sequentially fabricate its respective work products based on the order in which *kanbans* were received, incorporating the material purchased first. Despite adaptations of the *kanban* system in the automotive industry and industries abroad, effective management cannot be realized unless the aforementioned rules are adhered to.

Just-in-time production and the *kanban* system are not without their faults, particularly when considering Toyota's dependence on its global supply chain. Toyota's Supplier Partnering Hierarchy emphasizes "mutual understanding and trust, interlocking structures, control systems, compatible capabilities, information sharing, joint improvement activities, and *kaizen* and learning" (Dudovskiy, 2012). Yet despite close integration, unforeseen circumstances, such as "a spike in demand for a particular product in a regional market, an act of war or terrorism, a regulatory change, … supplier bankruptcy," or natural disaster can adversely impact Toyota's ability to import components and maintain production schedules under the just-in-time strategy (Marchese & Lam, 2014). In the absence of controlled inventories to procure resources when unanticipated supply chain disturbances transpire, production schedules undoubtedly suffer. As a prime example, in March 2011, an earthquake measuring 9.0 on the Richter scale struck northern Japan, effectively disabling key Toyota suppliers for up to six months; as a result, manufacturing plants located in China and North America ceased operations, causing global production to fall by 29.9%. In light of such challenges, Toyota re-configured its organizational focus on proactive, diversified supply chain management as a risk mitigation tactic, assimilating its focus with core operational strategy. Furthermore, Toyota has diligently worked to implement anticipatory supply chain technology capable of "signaling disruptions or unexpected activity in remote corners of the world [to] … trigger appropriate adjustments in the flows of materials," while also pioneering additive manufacturing, or three-dimensional printing techniques, to in-source manufacturing processes previously existing outside of Toyota's factories (Marchese & Lam, 2014).

Tools and Tactics of Lean Organizations

The predominant goals of lean strategies are tri-fold in nature, beginning with the improvement of product and/or service quality, cost reduction of supplying the product and/or service, and the minimization of lead time required to deliver the product and/or service (Imai, 2012). The amalgamation of quality, cost, and delivery (QCD) are comprehended from a holistic perspective, integrating the operations of each functional unit within the business to satisfy customer requirements. Modern adaptions of QCD frequently incorporate safety and workforce morale as determinants of organizational success.

Quality

The quality parameter is often understood in Western manufacturing as the final product and/or service being provided to the customer, or the *result quality*. According to Imai (2012), lean mentalities extend such a perspective to encompass *process quality*, which refers to how the managerial staff identifies market opportunities and consumer needs, "convert[s] those needs into engineering and designing requirements, and eventually deploys this information to develop components and processes, establish work standards, and train workers" (p. 40). Contrasting a sole focus on reactive, statistical inferences such as parts per million defect rates or mean time before failures, a culture oriented toward process quality incorporates a human-centric, iterative cycle of standard maintenance and standard improvement related to the operations of "man, machine, material, method, and measurement" (Imai, 2012, p. 45). Operational standards are often perceived in American industry as constraints to individual discretion, as shackles of ingenuity and human creativity; however, standards developed through workforce participation and knowledge sharing represent "the best, easiest, and safest way to do a job" while offering the organization a means to evaluate system performance and gauge improvement initiatives (Imai, 2012, p. 54).

Lean culture drives the deployment of operational standards according to a robust framework referred to as the plan, do, check, act cycle (PDCA), which contextualizes change initiatives in the scope of quality, cost, and delivery improvements for both internal and external customers. Within the planning phase, a performance gap in the current process is targeted for improvement. To replicate the scientific method in relation to problem identification and analysis, Toyota pioneered the A3 reporting style, which refers to the internationally-recognized standard for an 11-by-17-inch piece of paper (Weber, 2010). Although each A3 report is comprised of its own unique visual management and story-telling tactics, the traditional structure begins with a succinct and unique theme to classify the change initiative. The report delves into the current operational condition while emphasizing the deficiencies using both qualitative and quantitative metrics. Target goals and objectives for *kaizen* activities are identified and juxtaposed against ramifications related to quality, cost, and delivery; effective objectives express a high level of specificity and measurability as a means to evaluate attainment. *Kaizen* teams, typically comprised of cross-functional change agents who possess direct experience with the targeted operational procedure, publish discoveries from root cause analyses on the A3 report; such problem-solving strategies utilized to conduct a root cause analysis include value-stream mapping, ishikawa diagramming, and five-why questioning. A sample value stream map and ishikawa diagram related to the forthcoming case analysis of Fitzpatrick Manufacturing Company are provided in Figures 3 and 9 of the Appendix, respectively. As a means of developing a vision for change, target conditions are identified to bridge the performance gap alongside an implementation plan detailing a timeline for completion, personnel responsible for executing process changes, and evaluative measures to validate the effectiveness of newly-applied standards. Characteristic of the Toyota approach, "the A3 process standardizes a methodology for innovating, planning, problem-solving, and building foundational structures, …. [The goal is] a broader and deeper form of thinking that produces organizational learning that is deeply rooted in the work itself" (as cited in Weber, 2010). The PDCA approach is cyclical in nature, meaning that "no sooner is an improvement made than the resulting status quo becomes the target for further improvement" (Imai, 2012, p. 5). The recurring exchange between quality standardization and quality development remains the highest priority of lean manufacturing organizations to sustain a competitive advantage. Refer to Figure 10 in the Appendix for the A3 report developed during the Fitzpatrick Manufacturing Company *kaizen* project.

Cost

The lean management strategy emphasizes a sharp distinction between cost cutting and cost management. As defined by Imai (2012), "cost management oversees the processes of developing, producing, and selling products or services of good quality while striving to lower costs or hold them at target levels" (p. 44). Short-term solutions to financial challenges impacting the production line often translate to layoffs and terminations, but such activities "invariably disrupt the process of quality and ends in quality deterioration” (Imai, 2012, p. 44). Cost management is achieved primarily by eliminating waste, or *muda*, in manufacturing processes. Waste is classified into seven distinct categories, each of which is equally egregious to the efficiency of the production line: (1) overproduction, (2) inventory, (3) over processing, (4) waiting, (5) transportation, (6) motion, and (7) defects (Feld, 2001).

Perhaps the antithesis of just-in-time production, overproduction, otherwise known as push or batch production, does not represent the voice of the customer but rather, managerial insecurities in an organization’s adaptability to adjust production levels to meet fluctuations in market demands. One of the driving factors accompanying wastes of overproduction are needlessly extensive setup and changeover times. When an organization is in the midst of tooling changes, no value-added work is being completed and production schedules are not being fulfilled. To satiate such concerns, managerial instinct turns toward overproduction as a short-term solution to build a safety net of work-in-process and final goods inventories. Overproduction “results in tremendous waste: consumption of raw materials before they are needed, wasteful input of personnel and utilities, additions of machinery, an increase in interest burdens, the need for additional space to store excess inventory, and added transportation and administrative costs” (Imai, 2012, p. 80).

The waste of over processing is characterized by operating procedures encumbered by redundancies that do not provide value from the perspective of the customer (Feld, 2001). One of the most prevalent examples of over processing in manufacturing facilities are quality control checks. In an idealized environment, the integrity of a production procedure would be consistently upheld, generating reliable output that is free from defects and variation through every cycle. Chance variations in manufacturing conditions, operator competence, and machinery operability prevent the utopian order from being realized even within the Toyota Production System. However, investments in procedural standardization, employee training and development, total quality maintenance, and continuous improvement gradually streamline manufacturing phases to negate the waste of over processing.

The *muda* of waiting occurs “when an operator’s work is put on hold because of line imbalances, lack of parts, or machine downtime” (Imai, 2012, p. 84). Although not flawless, production levelling and just-in-time strategies strive to eradicate downtime by establishing a consistent flow of work throughout the manufacturing line.

Transportation waste is typically embodied by work-in-process movement within a manufacturing facility by means of trucks, forklifts, and/or conveyors, but it also encompasses the movement of information within the organization to facilitate operations (Feld, 2001). Keeping the focus on a production line, lean organizations champion the merits of work cell arrangements compared to line flows to consolidate manpower and material flows. Rather than descending through a linear line with excessive *muda* in conveyance, work cell arrangements localize related manufacturing operations into enclosed systems, each with standardized personnel ratios, cycle times, and in-process inventory quantities.

The *muda* of motion concentrates on human behaviors such as walking, lifting, reaching, bending, and stretching that are required to achieve production tasks; Imai (2012) purports that “any motion of a person’s body not directly related to adding value is unproductive” (p. 83). To comprehend the *muda* of motion, lean organizations observe the behavior of the production staff to ascertain how work cells can be designed to facilitate efficiency in operations as well as the ergonomic health and safety of workers. Frequent countermeasures include placing material delivered from the up-stream process adjacent to the worker and/or machine that will initiate the succeeding value-added task and ensuring that tools are stored in readily accessible locations.

The final categorization of *muda* is the production of defects, an element of waste that results in lost production time due to re-works, squandered material, and forgone time devoted to conventional production (Feld, 2001). The Toyota Production System attempts to alleviate this waste by installing machines equipped with autonomation, or the ability to detect abnormal production conditions and cease manufacturing to circumvent generating defects, or *gembutsu* (Ohno, 1988). In mass-production manufacturing organizations lacking autonomation, time, material, and labor wastes associated with defects are amplified because a sizeable number of defective products are often spawned before quality control measures detect the abnormalities and signal the stoppage of the work process (Imai, 2012). To minimize the probability of reoccurrence, the lean methodology prescribes interdisciplinary root cause analyses of *gembutsu* for comprehensive problem identification. Once the root cause is determined, countermeasures in either work processing, machine maintenance schedules, or tooling designs are employed to negate future complications.

Contemporary research conducted by the Pawley Lean Institute in the publication, “Eight wastes” (n.d.) cites the underutilization of human capital as a final waste to be considered by lean organizations. Whether it be through a mismatch in the knowledge, skills, and abilities between job and personnel, inadequate training of employees to achieve higher standards, or failing to engage workers in the analysis and design of operational procedures to innovate work processes, ignorance of an organization’s human resources contradicts the people-centric approach of lean management strategies. A table derived from the “Eight wastes” (n.d.) publication provides further insight into the elements of *muda* that are encountered both in manufacturing and office-based organizations and is available in Figure 2 of the Appendix.

Delivery

The final overarching goal of lean production systems is the optimization of delivery to both internal, process-based customers and the final customer. More specifically, the delivery metric analyzes the lean organization's ability to consistently supply the intended good and/or service to the customer in the specified volume per the agreed upon timeframe listed in the purchase order or contract. Delivery schedule achievement is quantified according to the following formula developed by the Industry Forum of the Society of Motor Manufacturers and Traders (as cited in "QCD: Measuring manufacturing performance," n.d.):

$$Delivery\ schedule\ achievement = \frac{No.\,of\ planned\ deliveries - (No.\,not\ on\ time + No.\,of\ incorrect\ qty.)}{No.\,of\ planned\ deliveries}\ x\ 100$$

Of course, the target for any lean organization is the 100% attainment of delivery schedules, but it is worth noting that early deliveries are regarded as failures in the planned delivery requirements of customers. Early deliveries consume precious time in configuring floor space to cope with the unexpected, incoming material and adversely disrupt logistics queues.

Contemporary efforts by the Ford Motor Company to realize just-in-time production and curtail delivery schedules between internal production functions involve integrating suppliers within a centralized manufacturing campus as evidenced by its $1.90 billion Camaçari, Brazil complex established in 2001 (Weber, 2002). Marketed by Ford executives as the first auto plant operating per a "sequenced modular assembly system," the Camaçari plant assimilates Ford operations with those of thirty-three distinct partners that supply the assembly line with components in just-in-time fashion. A sample of its strategically unified supplier base includes companies such as Benteler, Lear, Valeo, and Dow. Because of the modular approach to assembly-line and tooling design, the plant is capable of producing six different vehicle models on the same line simultaneously. Adopting the assembly campus helps Ford to "increase flexibility, allow for quicker response to customer preferences, lower inventory costs, and help control shipping and capital costs," thereby making it a staunch competitor to Toyota's production system (as cited in Weber, 2002). The internalized network of suppliers reduces the average material travel distance from 450 miles to 125 miles, a 72.2% reduction, thus lessening final delivery schedules to the market. Furthermore, time and financial resources encumbered by domestic and international shipping, in-process storage and maintenance, and in-factory transportation are nearly eradicated under the assimilated approach.

The adaptation of the supplier campus model in the United States has been met with resistance on behalf of the United Auto Workers (UAW), "which has historically opposed such extensive supplier integration on the factory floor" (Weber, 2002). Because of the collaborative nature of the manufacturing campus, ensuring the definitive separation of duties between companies and their respective bargaining units is a challenge. Additional challenges include maintaining a workforce in light of wage discrepancies between tiers of suppliers and the mother-company. For example, line assembly workers at a supplier average $12 an hour, while a comparable position at Ford earns $20 per hour. Despite the perceived challenges, Ford successfully opened its first, United States-based manufacturing supplier campus in Chicago in 2004. Being awarded the Shingo Prize for Excellence in Manufacturing, a prestigious honor bestowed on companies exemplifying lean manufacturing principles, the 155-acre facility includes nine suppliers, some of which include Brose North America Inc., Comau Pico, Plastech

Engineered Products Inc., and ZF-Lemforder Corporation (Weber, 2002). Similar to its Brazilian counterpart, the Chicago-based facility's cost savings imparted by the integrated supplier network and lean sequence of operations is estimated to be $700 per vehicle. General Motors has undertaken similar efforts at its Gravataí assembly plant located in Brazil in which sixteen suppliers work alongside the automotive manufacturer; according to Weber (2002), "the supplier team that makes up the Gravataí complex represents 60 percent fewer suppliers and 50 percent fewer parts than would be necessary in a traditional manufacturing system." Future expansions of the supplier campus framework by American automotive manufacturers characterize innovative adaptions of lean methodologies to ensure competitive quality, cost, and delivery parameters in the global market.

Culture of Lean Organizations

Pertinent to the discussion of the tools and tactics indicative of lean organizations is the cultural orientation toward the *gemba,* or place where the value-added activities occur (Imai, 2012). Most commonly in automotive manufacturing companies such as Toyota or Ford, the *gemba* is the assembly line where discrete components are joined to form a vehicle. In service organizations such as restaurants, the *gemba* can be considered the dining room where customers come into contact with the wait staff or the kitchen where the meals are prepared; the focus of the *gemba* is satisfying customer demands by producing either a product or a service. Professor Takeshi Kawase of Keio University explained *gemba*-based organizational structure as follows:

> People within a company can be divided into two groups: those who earn money and those who don't. Only those frontline people who develop, produce, and sell product are earning money for the company. The ideal company would have only one person who does not

earn money – the president – leaving the rest of the employees directly involved in revenue-generating activity (as cited in Imai, 2012, p. 17).

Contrary to Western manufacturing firms which traditionally maintain tiered organizational structures with multiple layers of management residing atop the pyramid, lean culture considers the *gemba* the pinnacle of the business. Framed by Imai (2012) as the inverted triangle, "the regular management layers – top management, middle management, engineering staff, and supervisors – exist to provide the necessary support to the work site" (p. 15). Juxtaposing a *management of support* with a *management of control*, managerial responsibilities of establishing organizational policies and processes and allocating resources to achieve business objectives cannot occur without understanding the strengths and challenges facing the *gemba.* It is through the efforts of the *gemba* that an organization realizes its quality, cost, and delivery targets to satisfy the demands of the customer, so it becomes the obligation of the managerial staff to ensure the *gemba* is equipped with the appropriate resources and processes to achieve such objectives. Furthermore, lean organizations understand that continuous improvement activities related to manufacturing processes must directly employ the knowledge and experience held by the *gemba* workforce through mechanisms such as quality circles or *kaizen* teams. Western institutions encumbered by hostile management-union relations are thwarted from such undertakings as managerial teams avoid involvement in *gemba* operations altogether due to fear of inciting grievances. In the historical Western mindset, a disparity in respect resides over managerial-union relationships, and management "tends to 'dump' its instructions, designs, and other supporting services – often in complete disregard of actual requirement" (Imai, 2012, p. 15). In the absence of constructive dialogue with the *gemba* workforce, continuous improvement of operational standards and processes is constricted and resistance to change is debilitating. Hence, lean production systems are distinguished from rigid applications of scientific management by incorporating a people-focused approach to problem solving and organizational culture change.

Dennis Pawley's Perspective on Lean Leadership

Dennis Pawley, former Executive Vice President of Manufacturing and Labor Relations of Chrysler Corporation and chief benefactor of the Pawley Lean Institute of Oakland University, was responsible for spearheading lean transformation initiatives at the automotive firm between 1991 and 1999. Initially joining Chrysler in March of 1989, his rapid ascent to Executive Vice President of Manufacturing by December 1991 was accompanied by an amplified prominence on continuous quality improvement in the assembly plants as it competed with the quality and cost attained by its primary benchmark, the Toyota Production System (Brown, 1994). Fostering the framework that would later evolve into the Joint Activity Operating Principles, or the Chrysler Production System, Pawley's leadership espoused concentration on "lean manufacturing, quality assurances, standardization, repeatable processes, continuous improvement, just-in-time and sequential parts delivery, and pull system[s]" ("DaimlerChrysler Corporation's lean production," 2000). Reports published by *Automotive Intelligence News* (2000) indicate that between 1998 and 2000, Chrysler Corporation, then merged with Daimler-Benz to become Daimler Chrysler, reported "an estimated $300 million in favorable impact for the company" generated by its lean production system. Although impressive from a financial outlook, measures of organizational success were multi-faceted, considering safety, quality, delivery, cost, and morale as determinants of achievement.

Contradicting any perception of utopian imagery associated with organizational development, Pawley attests that "change is a war for people's minds, and no war was ever won without casualties" (D. Pawley, personal communication, March 9, 2018). For Chrysler, the causalities were embodied by a 35% - 40% turnover of C-level executives and middle managers whose thirty-year careers stagnated their approaches organizational management; those who were not able "to get on board" with the lean transformation and become change agents were asked to leave. To become an instrument of change, Pawley insists leaders must remain adaptable within the ever-competitive market and, more importantly, be able to teach; "if you can't teach, you can't lead" asserts Pawley. In his model of leadership, Pawley simplifies the equation for overcoming resistance to change, R, in the following formula:

$$D + V + F > R$$

Understanding the variables, change must begin with dissatisfaction with the current operational condition, *D*. Dissatisfaction can stem from any of the five key performance indicators, whether it be in safety, quality, cost, delivery, or workforce morale. Throughout his tenure at Chrysler Corp., Pawley took little satisfaction from celebrations of organizational success and rather concentrated on the problems preventing the company from becoming the automotive leader in producing, first and foremost, cost effective vehicles for the consumer market; "quality was a bi-product of the concentrated effort to produce world class, cost-effective vehicles" (D. Pawley, personal communication, June 4, 2018). Analogously explained by Brown (1994), "Pawley wants to hear about the hole, not the doughnut. Tell him about the problems, not, as he says, how great we are."

Effective leadership necessitates communicating a vision of what the organization can change to continuously improve, *V* (D. Pawley, personal communication, March 9, 2018). Comprehensive benchmarking of competitors' production systems and business analytics provide a tangible exemplification of how an organization can improve its quality, cost, and delivery metrics to become industry frontrunners. That is not to say that mimicking Toyota's production system is the answer to Western manufacturing firms' tribulations, as variances in cultural synergies would bode poorly under imitation, but adapting best practices provides a genuine case study of how the production line can advance. Cascading the lean transformation vision to the workforce, between 1998 and 2000, Daimler Chrysler sponsored "55, three-week Manufacturing Leadership Training (MLT) sessions at 54 facilities worldwide…. Each MLT activity, designed to improve quality and flexibility, while eliminating waste and excess cost, yielded an estimated average of $500,000 in favorable impact for the company for each facility, or a total of $25 million – all part of the company's $300 million efficiency gains" ("DaimlerChrysler Corporation's lean production," 2000). According to Pawley, such training was targeted for plant floor supervisors who would lead the transformation at the *gemba* and work in conjunction with the United Auto Workers to enact the management strategy.

The final element of the equation, *F*, refers to a leader's responsibility to take the first step toward the change initiative (D. Pawley, personal communication, March 9, 2018). Pawley explains that often people abide by the fallacious misconception that all managers are leaders when, in fact, the differentiator between a manager and an adaptive leader is the ability to implement change. Akin to Imai's (2012) division of production behaviors as either standard maintenance or standard improvement, managers are perceived by Pawley as keepers of the status quo. The true testament of a leader is to engrain change into the intellectual fabric of an organization. Many Western manufacturing firms adopt lean practices on a pull system, picking and choosing techniques such as quality circles or 5S audits while claiming to be lean-oriented (D. Pawley, personal communication, March 9, 2018). Although stepping stones for a developing enterprise, decision making and problem solving at all levels of the business, from the production floor to the executive suites, must be amended to harmonize with lean systems and techniques.

Coupled with an investment in workforce education, such change is achieved through a dissatisfaction with existing operational conditions, a compelling and realistic vision for future objectives, and managerial commitment to leading change.

Lean in Practice: A Case Study of the NUMMI Program

Arguably the decisive posterchild for the implementation of lean principles in American manufacturing, the New United Motor Manufacturing (NUMMI) joint venture between General Motors (GM) and Toyota, initiated in 1984 and dissolved in 2009, serves as a case study of how radically dissimilar organizational cultures can amalgamate to create an innovative hybrid (Wilms, Hardcastle, & Zell, 1994). To provide a standard description, organizational culture, as defined by Wilms et al. (1994) refers to the "set of assumptions and beliefs… guiding individuals' day-to-day working behavior." Located in Fremont, California, the NUMMI facility was originally established in 1962 under the sole ownership of GM. Rampant with disorder, the facility was notorious for authoritarian management spawning severe union conflicts, the presence of alcohol and drugs on-site, and "daily absenteeism [that] usually reached 20 percent" (Wilms et al., 1994, p. 101). The facility was closed by GM in 1982; at that time, "more than 6,000 grievances remained backlogged in the system" (p. 101).

The NUMMI project was developed reflecting the self-interests of both Toyota and GM. For Toyota, NUMMI represented the company's initial foothold in the American automobile manufacturing market; escalating import restrictions, taxation, and political pressures contributed to Toyota's business case to produce vehicles in the United States. Furthermore, Toyota was interested in learning how to adapt the Toyota Production System "to work with U.S. suppliers, U.S. government regulations, and, most importantly, the UAW" (Gomes-Casseres, 2009). From GM's perspective, the company planned to learn lean production strategies firsthand that it could later translate to its domestic manufacturing facilities. Such high-level strategies derived from the Toyota Production System included making each employee responsible for product quality between upstream and downstream operations by empowering individuals to stop the line when defects occurred, standardizing work practices within job functions, and implementing a just-in-time delivery system (Wilms et al., 1994). Furthermore, GM was introduced to the concept of production levelling through the standardization of *takt* time, which refers to the length of time assigned to perform a production function; initial scheduling enforced a time of sixty seconds per operation. Expanding its market share into the small vehicle segment, the NUMMI plant incorporated the production of a small car line, the Chevrolet Nova, and later the Geo Prizm, which was modeled after the Toyota Corolla (Wilms et al., 1994).

From the onset of the partnership, a great deal of negotiation between GM, Toyota, and the UAW revolved around the terms and conditions of the collective bargaining agreement. Although Toyota agreed that the venture would re-employ the majority of workers who previously served at NUMMI and recognize the UAW as the principal collective bargaining representative, Toyota championed an intensive job application screening procedure that set expectations for the returning workforce regarding behavioral standards and the newfound organizational values (Wilms, et al., 1994). Alignment between the leadership teams of GM, Toyota, and the UAW made such efforts conceivable as a commitment to minimizing adversarial relationships while building mutual trust and good faith were core objectives. Driving the employment function, 5,000 applications were sent to former GM employees “with a letter explaining how new employees would be expected to contribute to an atmosphere of trust and cooperation and that poor quality workmanship and absenteeism would not be tolerated” (Wilms et al., 1994, p. 104). Of the 5,000 letters sent, 3,000 employment applications were returned, and 85% of the revitalized NUMMI workforce were previously employed at the Fremont facility.

As aforementioned, a glaring cultural difference between Japanese and American organized labor is the separation of production functions into distinct labor classifications and/or bargaining units. At NUMMI, GM and the UAW historically categorized labor into 80 job classifications with varying union wage structures to support the division of labor. As a precondition for the joint venture, the labor classifications were consolidated into three categories, “one production class and two higher-paid skilled trades classes” (Wilms et al., 1994, p. 105). Such a system aligns with Ohno’s (1988) conception of cross-training and adaptability between labor divisions as “in the Japanese system, an operator has a broad spectrum of skills… and participate[s] in building up a total system in the production plant” (p. 14). To further model Japanese management practices, “a flat wage structure that equalized work and rewards while fostering fairness” governed the compensation system; the managerial team also instituted “a bonus system, based on gainsharing, that … reinforced the feeling that the company’s fortunes depended on everyone’s efforts” (Wilms et al., 1994, p. 105).

Aligned with Japanese communalistic values, the production system relied on a participative management style in which plant managers, supervisors, and individual contributors alike engaged in problem solving exercises to balance productivity with quality demands (Wilms et al., 1994). According to research published by Wilms et al. (1994), engraining the consensus style of decision making proved an immense psychological challenge as pressures mounting from line stoppages and impending production schedules often featured regressions to authoritarian management practices on behalf of GM line supervisors and team leaders. Furthermore, sustaining continuous improvement initiatives throughout natural cycles of workforce complacency and retrogression became challenges for the managerial staff; once production and quality goals were achieved, the workforce naturally relapsed in terms of performance and effort, thereby causing quality to suffer. To counteract this cycle, "Osamu Kimura, NUMMI's third president, described a constant need to 'renew the spirit' by finding problem areas and accelerating improvements" (Wilms et al., 1994, p. 106).

In light of the previous GM plant being closed and all production workers being laid off, employment security was a chief concern of the NUMMI workforce. In fact, during a 1994 survey of the revitalized production staff, "80 percent of the team members agreed that job security was the most important aspect of working at NUMMI" (Wilms et al., 1994, p. 105). In its purest form, Japanese culture instills communal values that extend to the employment relationship. According to Wilms et al. (1994), "Japanese workers make a lifetime commitment to their employers, but Americans lack this sense of belonging" (p. 109). Considered a meeting of the minds between cultural orientations, NUMMI's management staff initiated a no-layoff policy that was enforced "unless the long-term viability of the company" was at risk (p. 105). Further efforts to create a culture founded on respect and trust between management and the union included the elimination of all contract labor to preserve unionized employment in financial downturns and the mandate of executive pay cuts during production recessions. Between 1984 and 1994, such programs were employed on four separate occasions to preserve the integrity of the no-layoff program. Keeping in the *kaizen* spirit of continuous problem solving, alternatives to layoffs included workforce training on the production system, team relations, and *kaizen* events.

Early measures of the plant's productivity and quality far exceeded the facility's previous accomplishments under GM management. "In its first year of operation [1985], NUMMI assembled 64,766 Novas – a car that has been hailed by leading consumer magazines as one of the highest-quality small cars" (Wilms et al., 1994, p. 102). According to an article published by the *Wall Street Journal*, NUMMI had "managed to convert a crew of largely middle-aged, rabble-rousing former GM workers into a crack force that is beating the bumpers off Big Three plants in efficiency and product quality" (as cited in Wilms et al., 1994, p. 102). Personnel surveys of job satisfaction published metrics of 93% of employees taking pride in their accomplishments at NUMMI, and such findings were reflected in the absenteeism rate, which averaged 2% in 1985. The existence of a motivated and respected, multicultural workforce capable of swiftly identifying and solving problems to manufacture the highest quality automobile allowed NUMMI to match Toyota's quality standards achieved in Japanese plants by 1987. Production metrics for 1994 published by Wilms et al. (1994) reveal the plant produced 102,114 Corollas and 108,000 Geo Prizms. Keeping quality at the foundation of any work process in the manufacturing line, the "Geo Prizm and Toyota Corolla were ranked the best compact cars built in the United States" as heralded by J.D. Powers in 1993 (as cited in Wilms et al., 1994, p. 102). Between its opening in 1984 and 1994, the production facility underwent three major expansions which represented a $1.6 billion investment by GM and Toyota. Transitioning the plant from its initial focus on compact car production, Toyota chose NUMMI as the site to manufacture the Toyota Tacoma pickup truck in 1991 "largely because of the company's record for high productivity and quality" (p. 108). According to Wilms et al. (1994), expansions and line re-tooling to adapt the facility for pickup truck production amounted to $340 million in capital investment and an additional 900 employees to realize production goals.

Summarizing the principles upon which the hybrid culture was established, interdependence characterized the conditions of success for the NUMMI production facility (Wilms et al., 1994). Despite variances in cultural predispositions toward communitarian or individualistic values, conceptions of obedience to authority, empowerment on the production line, and language barriers, the NUMMI workforce was united under a collective vision of trust, cooperation, and high-quality workmanship that was communicated during the job screening procedure. Akin to Pawley's commentary on leadership taking the first steps to instill change in an organization, the innovative partnership between GM, Toyota, and the UAW exemplified mutual trust and good faith relationships throughout the negotiation proceedings that defined the work structure and processes during NUMMI's establishment. Research related to organizational development and change affirms that "a force great enough to induce change or 'unfreeze' an organization" is required to lead a transformation initiative, and that the force must be "powerful enough to overcome individuals' natural fear of abandoning their core beliefs for new ones" (Wilms et al., 1994, p. 111). Adverse employment conditions between 1982 and 1984 for previous GM-UAW employees certainly created the stark reality of what could occur if the NUMMI venture failed and contributed to the workforce's willingness to adapt to change. Educational investments by Toyota, which amounted to $3 million expended by sending 600 employees to Japanese Toyota facilities throughout NUMMI's early developmental years was crucial in leading by teaching. Peer influence also played a distinct role according to Kiley (2010), as those who returned from Japan "carried the message to skeptical workers that 'The Toyota Way' was better and would save their jobs." Furthermore, Wilms et al. (1994) affirms that "NUMMI's commitment to treating its workforce fairly, and Toyota's integrated production system that demanded participation, mutual respect, and trust" were leading incentives for change (p. 111). It is also worth noting that the production system instilled at NUMMI was not a direct replication of Toyota management practices, but rather a blended fusion of GM and UAW production principles. Rather than force the system on a skeptical workforce that had a history of poor management-union relations due to authoritarian management practices, Toyota and GM leaders realized the value of education, workforce training, participative management, and the existence of process ambiguity in integrating the NUMMI facility with the Toyota Production System.

Considering the impressive quality and productivity feats achieved throughout the joint venture, it bears to question why the NUMMI project ceased. GM pulled out of the project in 2009, partially for economic reasons related to its bankruptcy and partially because it had reaped the benefits of the partnership by developing its own Global Manufacturing System, a “direct copy of the Toyota Production System” which is considered “every bit as efficient as the Japanese automaker’s system” (as cited in Kiley, 2010). Operating the plant for approximately one year after GM’s departure at half capacity, Toyota decided to close the production facility in April 2010 which resulted in the loss of 4,700 jobs (Kiley, 2010). From Toyota’s perspective, the company achieved its initial objective of developing a viable manufacturing facility in the United States; in fact, as of 2010, it has operated facilities in Kentucky, Texas, Indiana, and West Virginia as well as a plant in Ontario, Canada. Furthermore, it is worth noting that the NUMMI plant was Toyota’s sole production facility with a unionized workforce, leaving separated workers to speculate that the collective bargaining relationship may have played an equally important role in the facility’s closure as did economic motives (Gonzales, 2010). In any case, the NUMMI experiment will continue to serve as an exemplary case study of organizational culture change and the adaptation of lean manufacturing principles in the American automotive industry.

Lean in Practice: A Case Study of Fitzpatrick Manufacturing Company

Fitzpatrick Manufacturing Company (FMC) is a build-to-print, CNC machine shop located in Sterling Heights, Michigan that specializes in high-precision turning, milling, grinding, and laser engraving. The organization maintains a diverse portfolio of customers including those in the oil, gas, and mining industries (40% of operations), robotics and motion control trades (24% of operations), and die and molded plastic productions (6% of operations), amongst others. The business employs 88 non-unionized workers and achieved $12 million in annual sales for the 2016 calendar year (K. LaComb & C. Day, personal communication, October 5, 2017). The organizational structure is hierarchical in nature with each of its nine, value-added production division supervisors reporting to a localized, General Plant Manager who then reports to the FMC's two Co-Presidents; non-manufacturing functions such as account management, finance, quality control, and logistics report directly to the Co-Presidents. Lacking a dedicated sales function, the organization cultivates close partnerships with its collection of long-term customers, some of which have been established for thirty years. In light of such relationships, FMC recognizes its vendor-managed inventory system as a competitive advantage that allows the organization to achieve rapid turn-around times to meet volatile customer demands, specifically for its oil and gas partners (K. LaComb & C. Day, personal communication, October 5, 2017). As a result, FMC does not process orders according to a just-in-time strategy, but rather employs a material requirement push system, or batch production, to maintain inventory stocks despite costs and *muda* associated with storage, transportation, maintenance, and opportunity costs of lost floor space. However, integrating lean culture into its manufacturing methods, FMC organizes three major and two minor cross-functional *kaizen* events each year to enhance its processes. With a managerial belief that "skilled people become the only sustainable competitive advantage," the staff undergoes approximately 700 hours of formal education each year related to work cell procedures, machine operations and safety, and lean green belt certifications ("Training and education," 2016).

The *gemba* is divided into thirteen work divisions, each specializing in a unique operation such as sawing, grinding, or in-process quality inspections; nine of the thirteen divisions are responsible for value-added, manufacturing functions and contain multiple machine cells (K. LaComb & C. Day, personal communication, October 5, 2017). The lifecycle of a project begins during FMC's advanced process quality planning (APQP) meetings in which department heads and division leaders corroborate to review product specifications, determine manufacturing feasibility, analyze inventory levels for repeat orders, review machine, manpower, material, and tooling requirements, and develop project schedules. From such discussions, a *kanban* is created in the form of a blue sheet which specifies the job's course through each manufacturing division, production quantity, delivery schedule, and method of manufacturing; the blue sheet is attached to the job box and travels with the order throughout each phase of its lifecycle. Although contrary to the ideal application of the *kanban* methodology, managerial discretion often dictates production schedules and inventories existing outside of the blue sheets (K. LaComb, personal communication, November 2017). Interdependence between production divisions creates an internal supplier network where the downstream process is the ensuing customer. Aligning each division's operations within FMC's value stream to maximize billable machine hours while reducing lead time poses an intricate challenge considering the organization's reliance on manual data tracking. Although equipped with a Microsoft Access database that is used to forecast jobs to manufacturing divisions, FMC does not have the resources to track production cycles within internal and external processes in real-time. Because of this condition, a great deal of time is expended during *kaizen* activities compiling historical data from purchase orders, blue sheets, shipping confirmations, and internal databases before analysis of its value stream can commence. In any case, managerial and workforce alignment on lean practices and *kaizen* culture are organizational strengths guiding FMC's operations in the competitive market.

As an educational partnership between Oakland University and FMC, the author and a team of four students championed a twelve-week *kaizen* workout between October 2017 and December 2017 at FMC. The problem of focus was customer-centric in nature and revolved around the lead time for slip-wicker production, a metallic wedge and locking mechanism used in oil drilling operations to fasten a drill pipe to the extraction site (K. LaComb & C. Day, personal communication, October 5, 2017). More specifically, the customer mandated a reduction in total lead time, measured from purchase order creation to final delivery at the customer's facility, from 56 days to 28 days. Consequences of not attaining the desired lead time within two years of the directive, originally communicated approximately one-year prior to the student-led *kaizen*, included the in-sourcing of manufacturing by the customer. Such a loss would thereby result in an approximate 12% reduction in FMC's annual order in-take (K. LaComb & C. Day, personal communication, November 2017). To contend with the customer's demand, FMC's managerial team strengthened research and development initiatives related to CNC machine and tooling capabilities to decrease cycle times, renegotiated queue times for its external, sublet services, and expanded its vendor-managed inventory for the slip-wicker product line.

The production process for slip-wickers is divided into thirteen operations listed in the table below; each operation is classified into one of three categories: (1) value-added, (2) auxiliary, and (3) sublet service. Value-added operations refer to tasks that physically modify the material to create the slip-wicker according to the customer's specification. Auxiliary work refers to operations that are required to process the job but do not add value to the final product. The two sublet services, heat treatment and induction hardening, are operations performed external to FMC. During these phases, the compositional structures of the slip-wickers are augmented by heat and electromagnetic hardening, respectively. Data related to the average number of days in each operation was compiled from the blue sheets and cost data sheets of eight purchase orders placed between August 2016 and July 2017. Where the average days in operation is reported as zero, the order entered and exited the operation on the same day. The unit of measurement is provided on the blue sheet as a date, thereby negating a higher specificity of minutes within each operation. The time for Operation 130 – Shipping is estimated using time elapsed until Operation 120 – Packaging subtracted from purchase order fulfillment. Where the average days in operation is listed as "N/A," FMC did not record data.

Operation #	**Operation name**	**Classification**	**Average days in operation**
Front office	Raw material order & reception	Auxiliary	7.3
Operation 10	Raw material sawing	Auxiliary	N/A
Operation 20	Turning	Value-added	7.1
Operation 30	Quality inspection A	Auxiliary	0.0
Operation 40	Heat treatment	Sublet service	7.9
Operation 50	Receiving quality inspection	Auxiliary	0.0
Operation 60	Induction hardening	Sublet service	9.9
Operation 70	Quality inspection A	Auxiliary	0.9
Operation 80	Mori (dimensioning & incisions)	Value-added	7.8
Operation 90	Quality inspection A	Auxiliary	0.1
Operation 100	Milling & grinding	Value-added	7.9
Operation 110	Quality inspection A	Auxiliary	0.0
Operation 120	Packaging	Auxiliary	3.4
Operation 130	Shipping	Auxiliary	2.5

Within the sample, the average lead time was 54.8 days, a value 48.5% greater than the customer-mandated lead time of 28 days; understanding the short-term duration of the student-led *kaizen* exercise, the team targeted a lead time reduction of 10%, which equated to 5.5 days. Intertwined with the lead time diminution, the *kaizen* team also encountered areas of opportunity related to non-integrated data collection and a lack of visual management during *gemba* visits, value stream mapping initiatives, and dialogue with employees. Specifically concerned with data collection, hand-off points between operations were recorded onto four, separate systems: (1) the job list database, (2) cost data sheets, (3) the quality inspection database, and (4) blue sheet *kanbans*. Access to real-time analytics related to what operation a job was in, what type of machine it was running on, and what personnel were involved in the manufacturing process was non-existent. Such information is integral to developing predictive models of FMC's value stream during the advanced process quality planning phase and is advantageous for evaluating the team's performance against a modeled standard. Furthermore, hand-off points between internal machine cells, quality inspections, and external sublet services were not traced using timestamp functionality, meaning that the precision of value stream analyses relied on ambiguous dates. For example, average metrics published in the table above for Operation 30 – Quality inspection A, Operation 50 – Receiving quality inspection, and Operation 110 – Quality inspection A read 0.0 days because the assessments were completed the same day the slip-wicker entered the operation; however, information detailing the number of minutes the components spent in a queue and the number of minutes consumed by the inspection process were either not published or not made available to the *kaizen* team. From the human relations and organizational culture perspective, such a deficiency in precise performance measurements negatively influences the workforce's ability to understand production goals defined by the managerial staff and whether the efficiency of current operations is attaining such goals.

The *kaizen* team began the lean workout by requesting eight samples of slip-wicker purchase orders procured by FMC between August 2016 and July 2017 with the intent to create a value stream map for each job; a sample of the map created for job number 21839 is provided in Figure 3 of the Appendix. As aforementioned, each slip-wicker production schedule is comprised of thirteen operations which begin when material is received by FMC. Preliminary investigation was devoted to ascertaining if time variations existed in front house operations, which begin with the date the customer order is received in FMC's vendor management system. The average time between purchase order reception by FMC and when raw materials were ordered was 1.5 days, and the average time between raw material order placement and reception by FMC's logistics division was 5.8 days. Based on the data provided and the direction of FMC's Co-President, it was determined that front house operations would not be the object of focus for the *kaizen* study.

The manufacturing process commences with Operation 10 – Sawing in which the raw material is cut into the length indicated by the customer per the specification; to the detriment of the value stream procedure, FMC does not collect data related to the duration of the sawing operation. Internal focus transitioned to the sublet services, Operation 40 – Heat treatment and Operation 60 – Induction hardening. Firstly, the heat treatment function consumed, on average, 7.9 days of manufacturing time. Due to proprietary heat treatment technology, the operation is outsourced to Elkhart, Indiana via a third-party logistics firm; shipment time for a round trip can range from seven hours to ten hours depending on the number of orders received by the logistics company. Orders are sent by FMC as partial shipments typically three days per week so that FMC can enter the production queue of the heat treatment specialist. After the heat treatment process is complete, the slip-wickers return to FMC via the shipping company, are unloaded into FMC's bay, and enter a queue in the quality control division to complete Operation 50 – Inspection A before being sent to Operation 60 – Induction hardening. FMC utilizes one of its two box trucks to send the slip-wickers to the local, induction hardening service; the induction hardening process consumed an average of 9.9 days. Understood from the current condition process map provided in Figure 4 of the Appendix, the sublet shipping procedure comprises eighteen steps, six of which are *muda*, ten of auxiliary work, and two of which are value-added.

Cumulatively, the sublet services consumed approximately 32.5% of total lead time figuring the current state's duration of 54.8 days. Furthermore, the proprietary heat treatment procedure possessed by the Elkhart firm is akin to a monopolistic market share on FMC's slip-wicker production. Despite the presence of Detroit-based heat treatment facilities which would reduce time lost due to transportation by seven to ten hours on a single shipment, the managerial team of FMC elects a sustained partnership with the Elkhart firm. Given this condition, the *kaizen* team proposed implementing a self-shipping pilot program in which FMC designates one of its two box trucks to handle all shipments of slip-wickers to the heat treatment facility on a routine schedule. Despite additional costs incurred in personnel to operate the vehicle and overhead costs related to transport, an advantage of such a program is that FMC's project schedule will not be dependent on the services of a third-party shipping organization. FMC will subvert lost time due to the multiple stops taken by the shipping provider and gain a direct shipping route to the Elkhart facility.

Perhaps more importantly, the self-shipping program will allow FMC to transition Operation 50 – Inspection A from an in-house function to a mobile function, thereby eliminating *muda* of time consumed off-loading dunnage from the logistics truck, entering the components into the quality validation queue, and reloading the slip-wickers onto the FMC truck for shipment to induction hardening. Based on interviews with quality control personnel, the tests conducted during Operation 50 include a weight sample taken from each pallet and a hardness test of three to five pieces per container; under the proposition, such tests will be conducted by a trained, FMC truck driver prior to departure from the heat treatment facility with minimal capital investment in a portable hardness tester and a pallet jack with a weight sensor. Because FMC does not currently track timestamps for all hand-off points in the shipping process (i.e. departure time of the logistics truck from FMC and arrival at heat treatment, time spent in the heat treatment queue, total time to complete heat treatment per batch, waiting time at the heat treatment facility prior to return shipment to FMC, time entry into FMC's quality control queue, time to complete Operation 50, and waiting time at FMC prior to shipment to induction hardening), an exact measurement of time saved cannot be ascertained without more robust data. However, a conservative estimate by the *kaizen* team as corroborated with an FMC account manager place the time savings at one day in consideration of the 54.8 day sampled average. Represented by the proposed process map provided in Figure 5 of the Appendix, the total number of steps in the sublet shipping process will be reduced from eighteen to thirteen, three of which are *muda*, eight auxiliary work, and two of which remain value-added.

Continuing through the *kaizen* investigation, focus transitioned to the three, value-added procedures in the slip-wicker production value stream, Operation 20 – Turning, Operation 80 – Mori (dimensioning and incisions), and Operation 100 – Milling and grinding, each of which expend an average of 7.1 days, 7.8 days, and 7.9 days of the manufacturing process, respectively. After each operation, CNC machine operators are tasked with recording the following metrics: (1) machine cycle time, (2) machine setup time, (3) first article quality inspection, (4) in-process quality inspection, (5) operation close-out procedure, and (6) total machining hours. From preliminary analysis of Operation 80 - Mori, the work process exhibited a high degree of variability in minutes per piece production (sum of machine setup time, first article inspection, in-process inspection, and total machining hours divided by quantity of slip-wickers), ranging from 5.53 minutes per slip-wicker to 7.92 minutes per piece despite a constant machine cycle time of 4.75 minutes; for a graphical display of the variability in minutes per piece production, see Figure 6 of the Appendix. The primary drivers for such variation were tri-fold in nature, beginning with the setup time required of the machine, the experience level of the machine operator, and the ensuing success/failure rate through first article and in-process inspections. In fact, a similar degree of irregularity characterized the machine setup procedure; similar slip-wicker jobs exhibited a range of 5.8 hours in machine setup, with the highest value documented at 9.8 hours and the lowest time recorded at 4.0 hours. The current condition process map created for Operation 80 - Mori, provided in Figure 7 of the Appendix, is segmented between front house operations and when the division leader receives the *kanban* to begin the work order. The entire process is represented in forty-four steps, twenty-four of which are *muda*, fourteen of auxiliary work, and six which are value-added.

Given this inconsistency, the focal area became the CNC machine setup phase, which is sub-categorized into ten tasks as shown in the current condition section of Figure 8 provided in the Appendix. Once the *kanban* is submitted to the division, the division supervisor or senior CNC operator examines the attached specification to understand the dimensions and incisions required per the work order; such information is essential in selecting the proper tooling, jaws (mechanical devices that hold the slip-wicker in the machine while incisions are made), and CNC program. For repeat job orders, FMC maintains a database of programs searchable by unique identifiers that can be electronically uploaded to compatible machines from a centralized computer. Furthermore, FMC maintains standardized tooling and jaw boxes that house the manufacturing utensils for recurring jobs such as the slip-wicker. During the *kaizen* team's observation of a machine setup procedure, it was discovered that a routine maintenance schedule was not standardized for such job boxes, meaning that a machine operator will lose time on a production schedule replacing tooling or cutting new jaws if the existing devices in the box are worn beyond use. A recommendation for improvement in this regard is implementing a weekly monitoring and maintenance schedule of the jaws and perishable tooling to proactively address the viability of production resources.

However, continuing through the machine setup process, once the program is received by the machine, the operator touches off each tool to calibrate the system with respect to zero points. An initial test unit is run through the machine, its dimensions are verified by the operator to certify alignment with the specification, and the first article is sent to the quality division for thorough analysis. If approved, the first article will receive a confirmation *kanban* manifested in a sticker, and production to blue sheet specifications commences. Failure during the first quality inspection results in machine re-calibration for part failure parameters and re-submission to quality control. As corroborated by the Co-President and a senior CNC machinist, knowledge and experience deficits within the workforce are chief determinants of a CNC machine operator's ability to efficiently coordinate a viable machine setup. Knowledge deficits attributable to the variance in machine setup times observed during Operation 80 – Mori are partially explained by the company's talent management approach. FMC champions a recruitment strategy of employing machinists with little to no experience and training them internally; however, internal training resources become limited when high-volume production orders are attained during business peaks when human resources are in high demand, thereby resulting in less efficient work performance as indicated in the variance in machine setup time, minutes per piece production, and success rate through first article inspection (K. LaComb & C. Day, personal communication, October 5, 2017). Furthermore, deficits in standardized work instructions related to machine setup and visually-communicated performance targets drive inconsistency in operations.

However, the principal recommendation to achieve a higher degree of consistency in the machine setup and ensuing minutes per piece production metrics involve creating customer-centric value streams within the three, value-added operations of slip-wicker manufacturing. To attain such a vision, the Co-Presidents are advised to determine the current consumption of in-house machining hours and projected order in-take for each of its long-term customers. FMC operates in a multitude of diverse industries ranging from oil, gas, and mining, agriculture, medical, robotics and motion control, and defense applications. Due to its dependence on recurring orders, the organization has pursued a business model of accepting any work order that comes through the door (K. LaComb & C. Day, personal communication, October 5, 2017). Because of such variability in product lines, FMC's capital and human resources are scheduled according to a grocery store methodology in which *kanbans* are sent to whichever work cell is readily available when the job reaches the respective operation in the value stream. Such a model places little emphasis on assigning jobs to machines based on tooling and material commonalities between work orders, which thereby implicates extensive setup activities to exchange tooling and machine programs. Adopting a perspective realignment, the *kaizen* team recommends categorizing such customers into a three-tiered classification system based on consumption of total machine hours, order in-take forecasts, and expected profit. For repeat job orders classified into the first tier, or the highest priority, customer-centric value streams will be designated based on CNC machine capabilities, qualifications of machinists, and- tooling and material commonalities within each production function. For example, the Operation 80 – Mori division may be comprised of ten CNC machines and ten machinists that share tooling stored at a localized hub. Under the current grocery store system, each machine and its respective machinist may be assigned a work order within FMC's entire product portfolio; such a design champions adaptability within the division at the expense of frequent tooling changeovers and highly variable machine setups. Under a specialized, customer-centric value stream, a single CNC machine and machinist will be designated to produce slip-wickers, for example. From the proposed condition process map provided in Figure 8 of the Appendix, the machine setup function is reduced from ten steps to four steps, and the primary responsibility of the machine operator is to adjust the tooling and CNC program before running the test unit rather than removing old tooling, retrieving and installing new tooling, uploading the CNC program, and calibrating each tool with respect to the zero points.

Understanding that time is the core metric, data derived from cost data sheets related to slip-wicker production indicated the historically-low setup time of 4.0 hours for a two-machine cell in Operation 80 is achievable when similar production requirements between job orders, limited tooling exchanges, and highly experienced personnel occur simultaneously; such findings were corroborated with the Co-President and a senior machinist. The recommendation of the *kaizen* team is to regulate such conditions by limiting the variability of resource and personnel involved in a machine setup and standardizing a setup target of 4.0 hours for slip-wicker jobs by implementing customer-centric value streams. Recall that sample data indicated a range of minutes per piece production of 5.53 to 7.92; such metrics are calculated by taking the sum of machine setup time, first article inspection, in-process inspection, and total machining hours and dividing by the quantity of slip-wickers manufactured. The objective is to standardize work practices under the value stream model to attain a standardized manufacturing time of 5.53 minutes per piece.

Normalizing 5.53 minutes for a sample production run of 1,000 pieces consumes a projected 92.16 manufacturing hours. Because FMC operates according to a 19-hour work day, the time in Operation 80 can be realized as 4.85 days, a reduction of 2.95 days compared to the sampled average. Implementation of the customer-centric value stream methodology will consume production down time considering shutdown for machine cells and tooling reorganization. Analysis of total lead time reduction for slip-wicker production is dependent on the integrity of FMC's data collection to determine the success and sustainability of the pilot program.

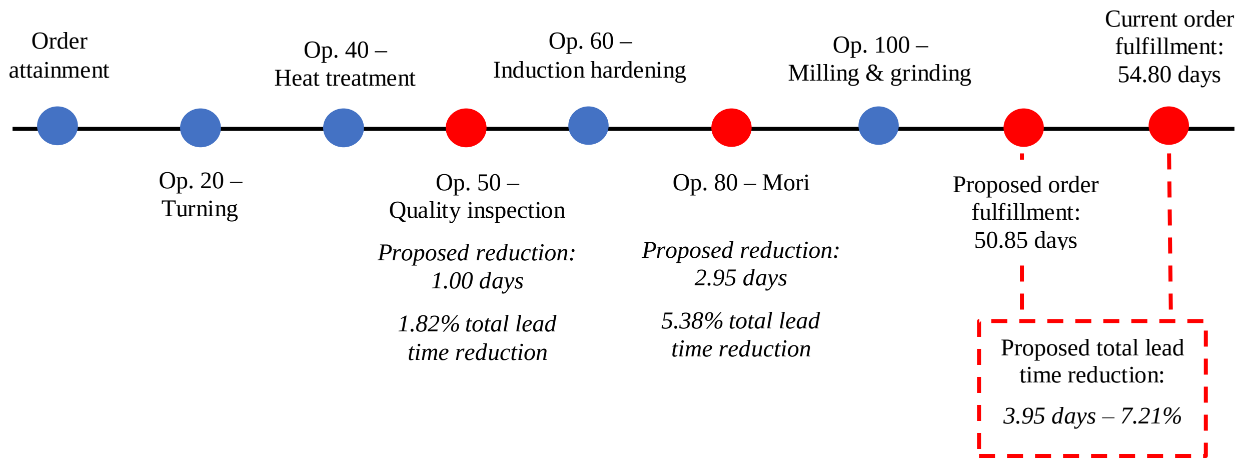
In summation, the *kaizen* team was faced with reducing the total lead time, measured from purchase order reception in FMC's vendor database to final delivery, of its slip-wicker portfolio of products from 56 days to 28 days, a 50% lead time reduction. Such a reduction was mandated by a customer operating in the oil and gas industry who comprises 12% of FMC's annual order in-take (K. LaComb & C. Day, personal communication, November 2017). The production process for slip-wickers is comprised of thirteen, unique operations, three of which are value-added, eight that are auxiliary work, and two operations that are external, sublet service functions. Sampling from eight production runs of slip-wickers occurring between August 2016 and September 2017, FMC's average lead time is 54.8 days, a value 48.5% greater than the customer's mandate; existing efforts to meet the customer's demand primarily embodied expanding the vendor-managed inventory. Furthermore, data collection to track the flow of a project was segregated into four, non-integrated systems: (1) the job list database, (2) cost data sheets, (3) the quality inspection database, and (4) each job's blue sheet; such a reality created immense challenges in ascertaining the production flow of the job throughout each division due to the lack of precision in measurements, non-uniform data collection standards, and purchase orders being divided into partials, thereby creating non-linear production patterns.

The objectives for the *kaizen* project were tri-fold: (1) reduce the lead time on 13 operation slip-wicker jobs by 10% of the 54.8-day average, equating to 5.48 days, (2) integrate the four data collection architectures employed by FMC into a single database that records all hand-off points between operations, and (3) implement visual management techniques to communicate time-centric performance objectives for slip-wicker manufacturing. The two principal activities aimed to curb the lead time for slip-wicker production were a self-managed shipping pilot program and creating customer-based value streams within the three, value-added manufacturing divisions, Operation 20 – Turning, Operation 80 – Mori, and Operation 100 – Milling and grinding.

The self-shipping program will manage FMC's shipments of slip-wickers to its external sublet services, Operation 40 – Heat treatment and Operation 60 – Induction hardening. The primary advantage of such a design is that Operation 50 – Inspection A is converted from an in-house to mobile process by training logistics personnel to conduct the quality measurements. A conservative prediction of lead time reduction is one day, or 1.82% of total lead time.

The second initiative involves categorizing FMC's customer portfolio into a three-tiered priority schedule, and designating tooling, machine, and personnel resources to product lines in tier one. Because the nature of FMC's business is dependent on repeat job orders, assigning work to internal value streams based on part specifications, tooling, and material commonalities will reduce time devoted to machine setup operations which are the primary driver of variation in minutes per piece production (sum of machine setup time, first article inspection, in-process inspection, and total machining hours divided by the quantity of slip-wickers produced). Instead, with limited tooling exchanges and program modifications, machine setup time, which historically consumed between 4.0 and 9.8 hours, can be harmonized at the 4.0-hour target. From a personnel management perspective, highly experienced staff members will be localized to high priority, tier-one jobs, but mentoring and cross-learning programs can be integrated to minimize knowledge deficits within the workforce. Conservative estimates of time reductions are valued at 2.95 days compared to the sampled average, or 5.38% of total lead time.

Combining the self-shipping pilot program with the customer-centric value streams, the estimated total lead time reduction is 3.95 days, or a 7.21% decrease from the 54.8 day sampled average. Refer to the figure provided below for a graphical representation.



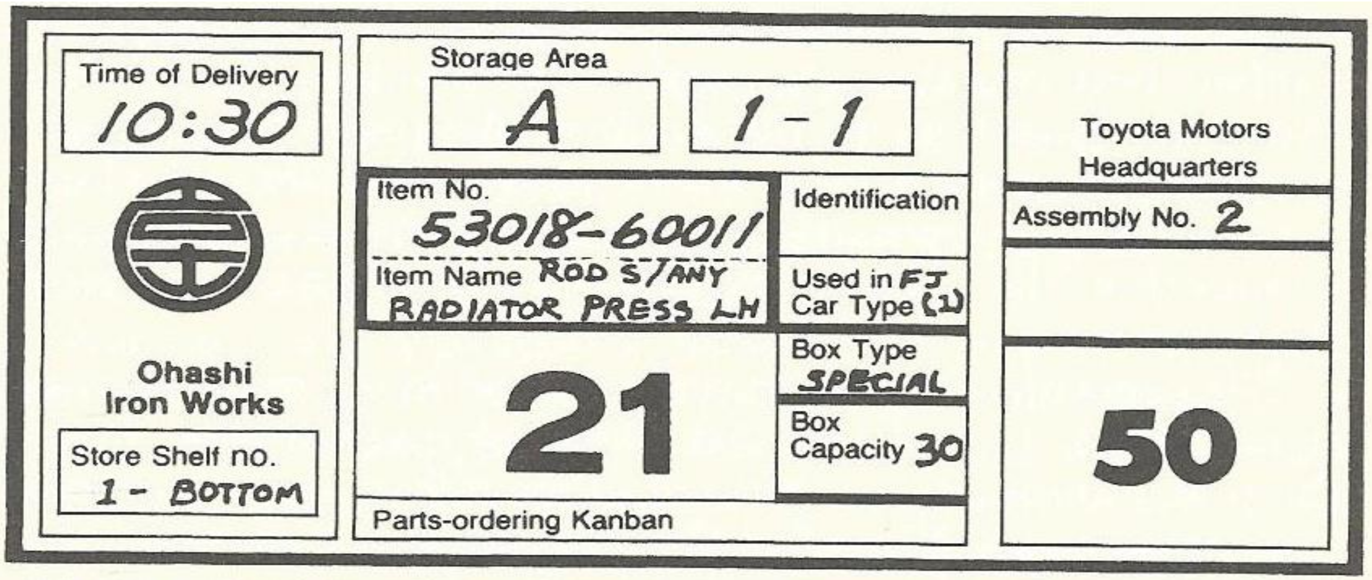
Intersected with mitigating lead time are standardizing FMC's data collection process and developing robust, visual management practices to empower the workforce to understand production priorities and goals. Firstly, the machine cost data sheets published in Operation 20 – Turning, Operation 80 – Mori, and Operation 100 – Milling and grinding must be integrated with the Microsoft Access job list database and quality inspection system to harmonize data collection. Metrics for all hand-off points between internal divisions and queue times for quality inspections must be recorded using timestamp precision; furthermore, hand-off points in the shipping process such as truck loading time, arrival at the sublet services, queue time at the sublet services, and time between order finalization and return shipment must be tracked to ascertain *muda*. Specifically related to evaluating the impact of the value stream organization of work cells in Operation 20 –

Turning, Operation 80 – Mori, and Operation 100 – Milling and grinding, the metrics of interest are machine setup time, first article inspection, in-process inspection, minutes per piece production, and total machining hours. Future technological considerations to sustain such a data-driven culture include incorporating a bar-code scanning system with QR code functionality within each division to create timestamps for each internal production function; the timestamps would be assigned activity codes by division leaders or other designated personnel to track the aforementioned manufacturing operations. Ideally, the database would support programming capabilities that could populate the job's data into a value stream map format for real-time analysis. Such a data collection system will translate to ease of reporting on machine setup, minutes per piece production, total machining hours, and lead time attainment for visual management practices. Division leaders would be responsible for debriefing the value stream machinists on historical performance and future targets to reinforce a transparent, team-centric organizational culture.

Throughout the *kaizen* exercise, the team relied heavily on data analysis related to eight purchase orders of the slip-wicker product. To understand the segregation between manufacturing divisions and FMC's quality management system, the team engaged in twelve *gemba* visits, conducted numerous employee interviews, and participated in a job shadow of the machine setup process in Operation 80 - Mori over the twelve-week period. The primary lean tools incorporated throughout the project included value stream mapping, Excel-based quantitative analyses, process mapping, ishikawa analyses, and the design of pilot programs to implement change according to the plan, do, check, act iterative methodology (PDCA). The complete A3 report published for FMC's lead time *kaizen* is provided in Figure 10 of the Appendix.

Appendix

Figure 1: Sample *kanban* used by the Toyota Production System (Ohno, 1988, p. 27)



When the Ohashi Iron Works delivers parts to the headquarters factory of Toyota Motors, they use this parts-ordering kanban for subcontractors. The number 50 represents the number of Toyota's receiving gate. The rod is delivered to storage area A. The number 21 is an item back number for the parts.

Figure 1. A Sample of Kanban

Figure 2: Eight wastes as published by the Pawley Lean Institute ("Eight wastes," n.d.)

Waste	Definition	Office example	Manufacturing example
Defect	Work that contains errors or lacks something necessary	• Incorrect information being shared • Data entry errors • Forwarding incomplete documents	• Scrap • Rework • Missing parts
Overproduction	Producing more materials or information than customer demand	• Creating reports no one reads/needs • Making extra copies • Providing more information than needed	• Producing more products than demand • Batch process resulting in extra output • Having a "push" production system
Waiting	Idle time created when material, information, people or equipment is not ready	• Ineffective meetings • Waiting for meetings to start • Files awaiting signatures/approvals	• Waiting for tools, parts, information • Broken machines waiting to be fixed • Raw materials not ready
Not Utilizing Talent	Not, or under, utilizing the talent of employees	• Insufficient training • High absenteeism and turnover • Inadequate performance	• Employing people in the wrong position • Not fully training employees • Missing improvements by failing to listen to employees
Transportation	Movement of materials or information that does not add value	• Hand carrying paper to the next process • Delivering unneeded documents • Going to get signatures	• Moving products around before shipping • Moving product from different workstations • Moving inventory around to take stock
Inventory	Excess materials on hand that the customers or employees do not need right now	• Purchasing excessive office supplies • Searching for computer files • Obsolete files or office equipment	• More finished products than demand • Extra materials taking up work space • Broken machines sitting around
Motion	Movement of people that does not add value	• Searching for files • Walking/reaching to get materials • Sifting through inventory to find what is needed	• Reaching to make adjustments • Walking to get a tool multiple times • Repetitive movements that could overwork/injure an employee
Extra Processing	Efforts that do not provide value from the customer's perspective	• Unnecessary signatures on a document • Making more copies of a document than will be needed • Saving multiple copies of the same file in multiple locations	• Adding unneeded value to a product • Using a more high-tech machine than needed • Extra steps to correct avoidable mistakes

Figure 3.1: Value stream map of FMC's slip-wicker manufacturing process (*Part one*)

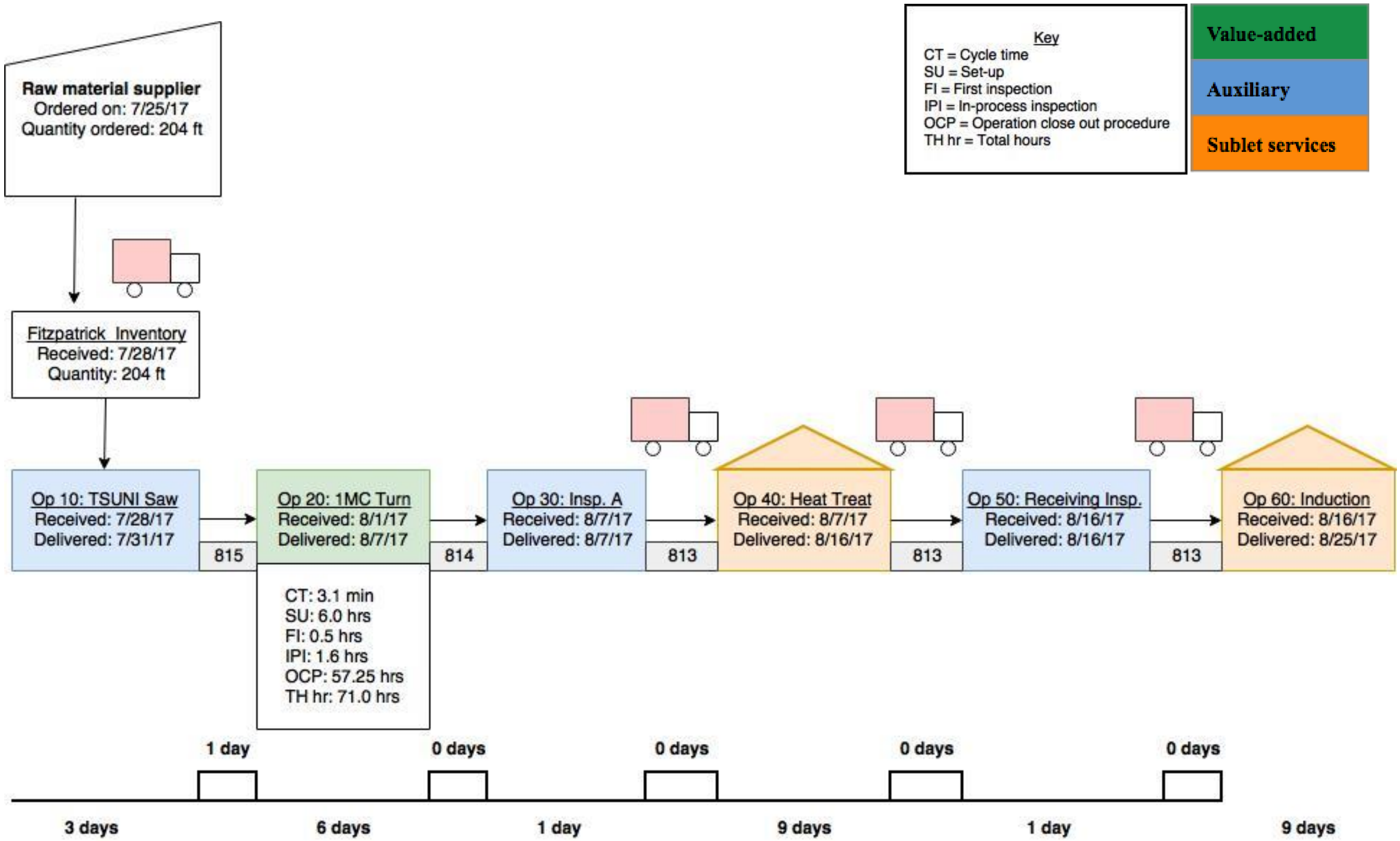


Figure 3.2: Value stream map of FMC's slip-wicker manufacturing process (*Part two)*

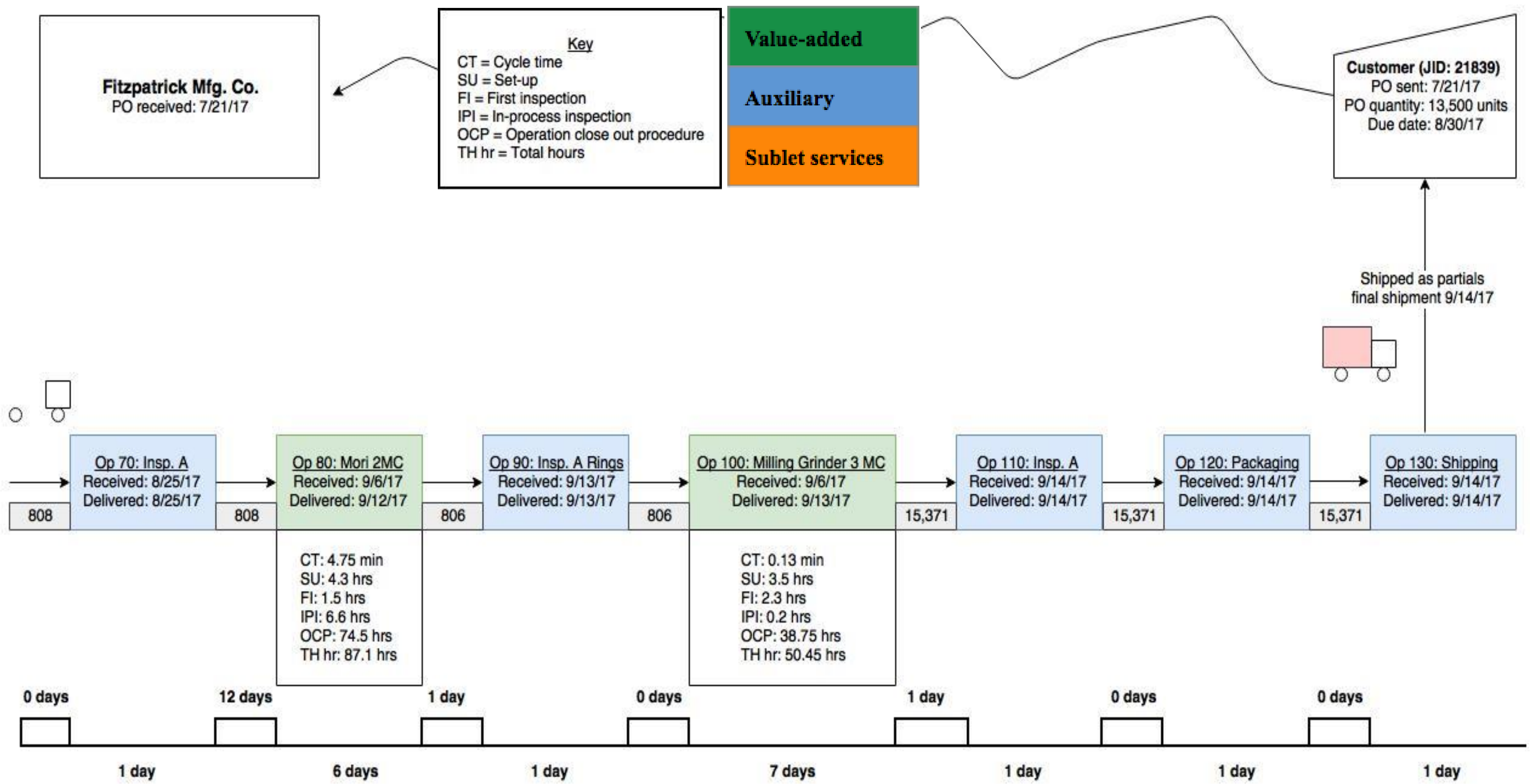


Figure 4: Current condition of FMC's sublet shipping process

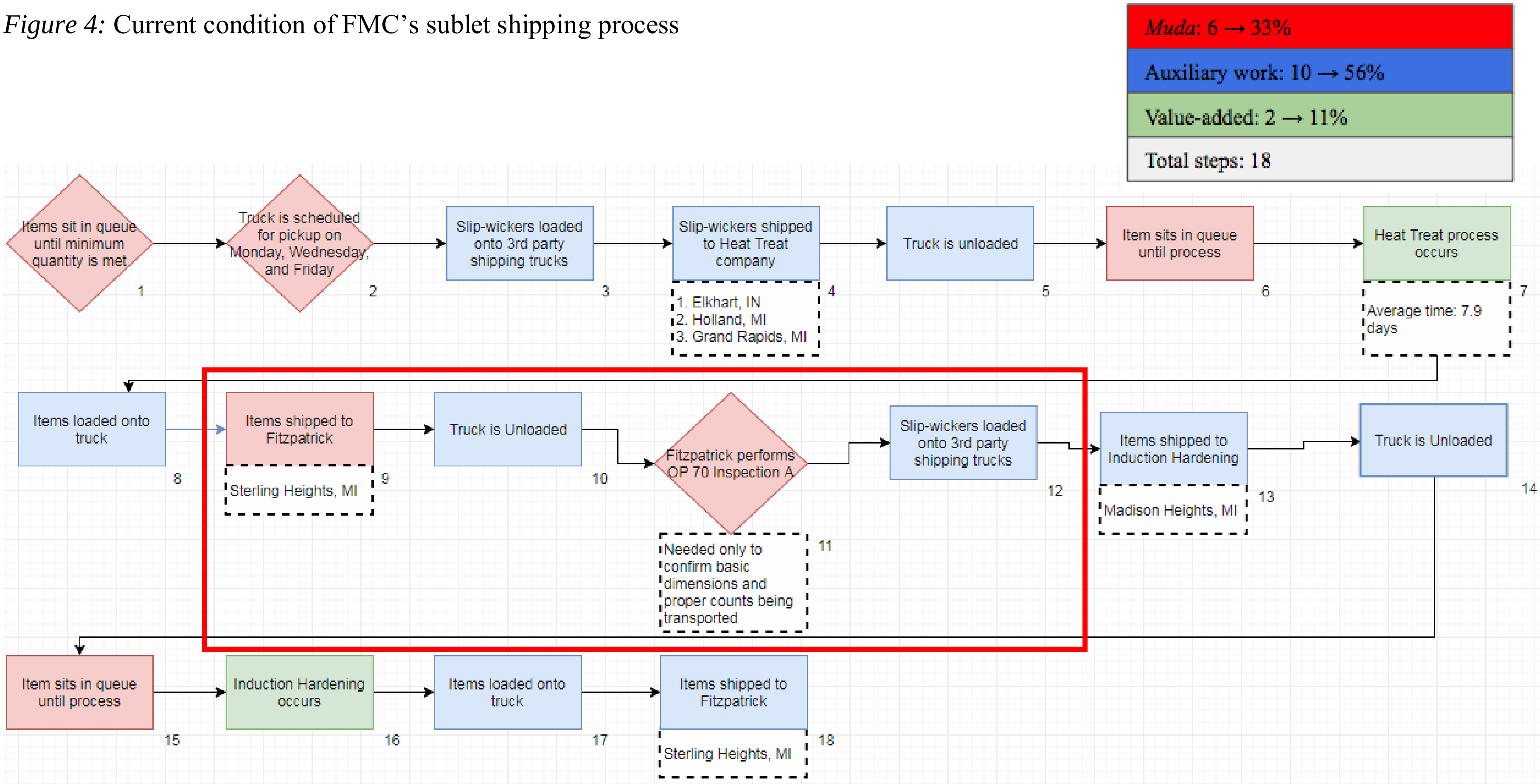


Figure 5: Proposed condition of FMC's sublet shipping process

Muda: 3 → 23%
Auxiliary work: 8 → 62%
Value-added: 2 → 15%
Total steps: 13

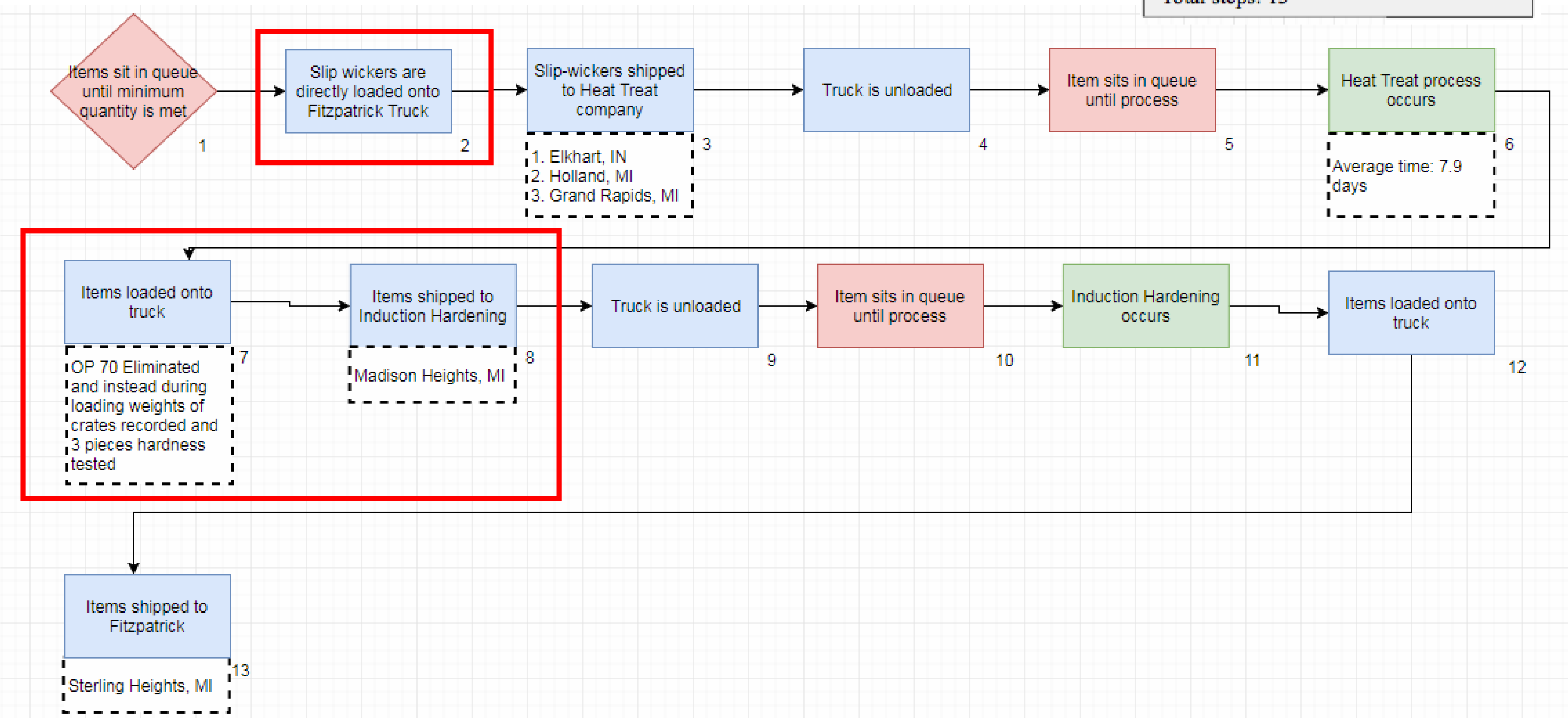


Figure 6: Variation in minutes per piece production within FMC's Operation 80 – Mori for eight job samples

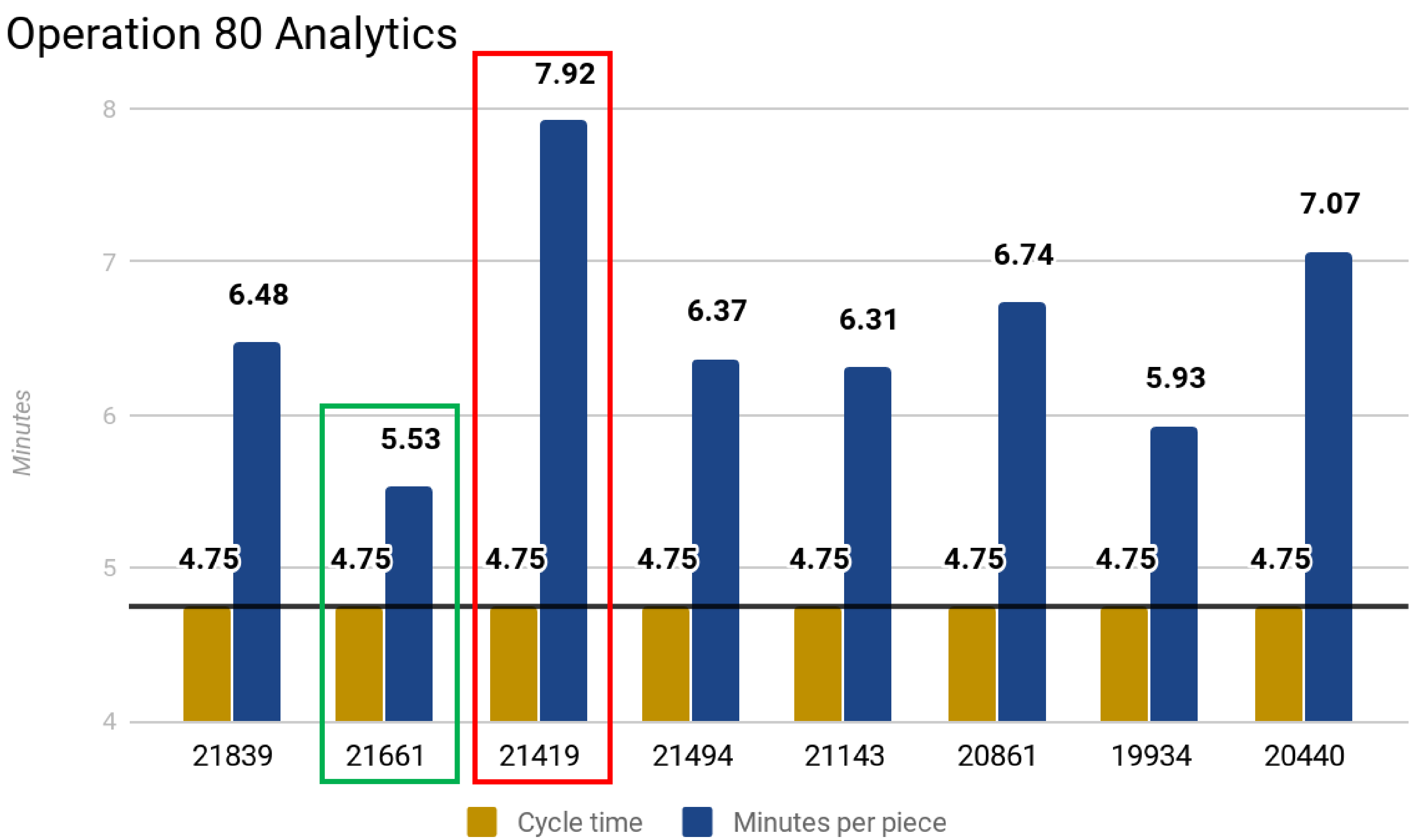


Figure 7.1: Current condition of FMC's Operation 80 – Mori manufacturing process (*Part one*)

Muda: 24 → 54%
Auxiliary work: 14 → 32%
Value-added: 6 → 14%
Total steps: 44

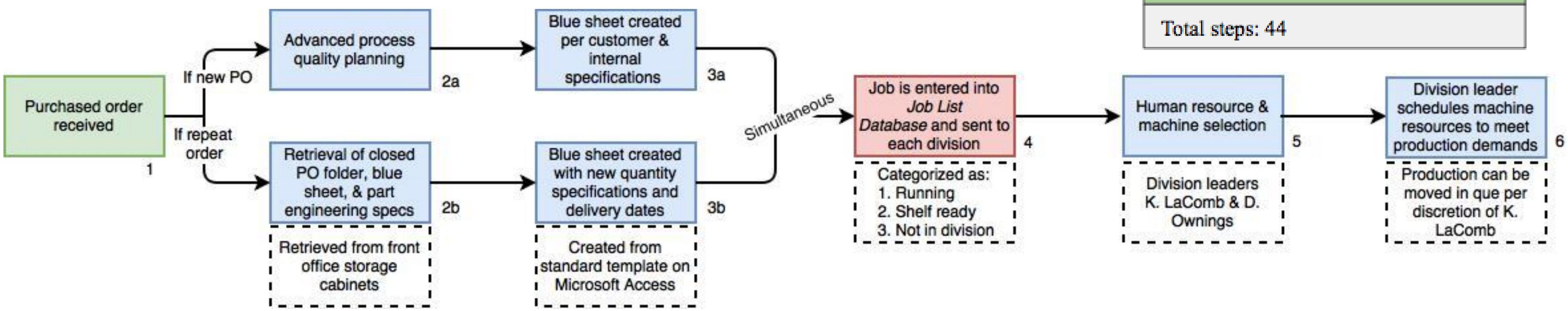


Figure 7.2: Current condition of FMC's Operation 80 – Mori manufacturing process (*Part two*)

Muda: 24 → 54%
Auxiliary work: 14 → 32%
Value-added: 6 → 14%
Total steps: 44

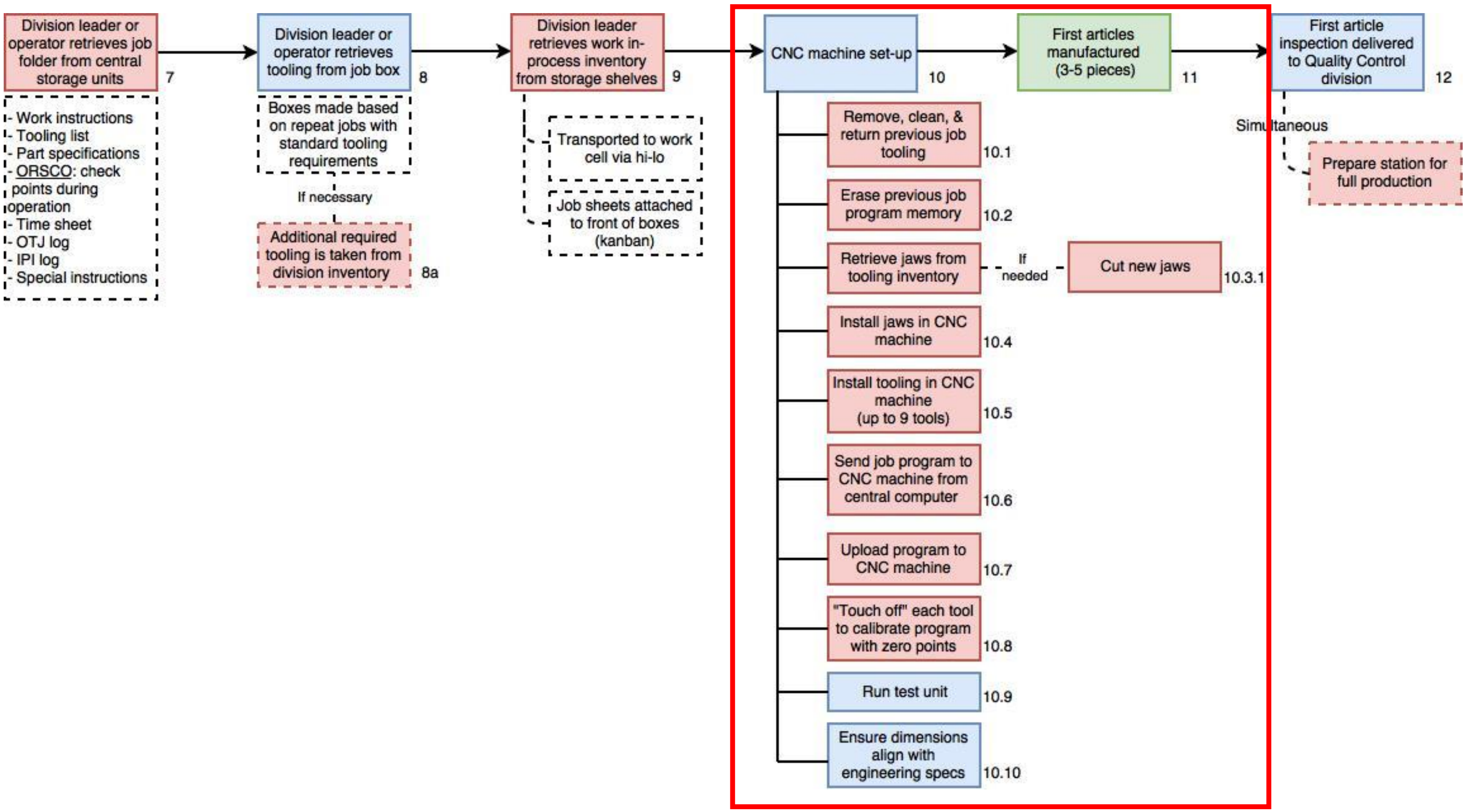


Figure 7.3: Current condition of FMC's Operation 80 – Mori manufacturing process (*Part three*)

Muda: 24 → 54%
Auxiliary work: 14 → 32%
Value-added: 6 → 14%
Total steps: 44

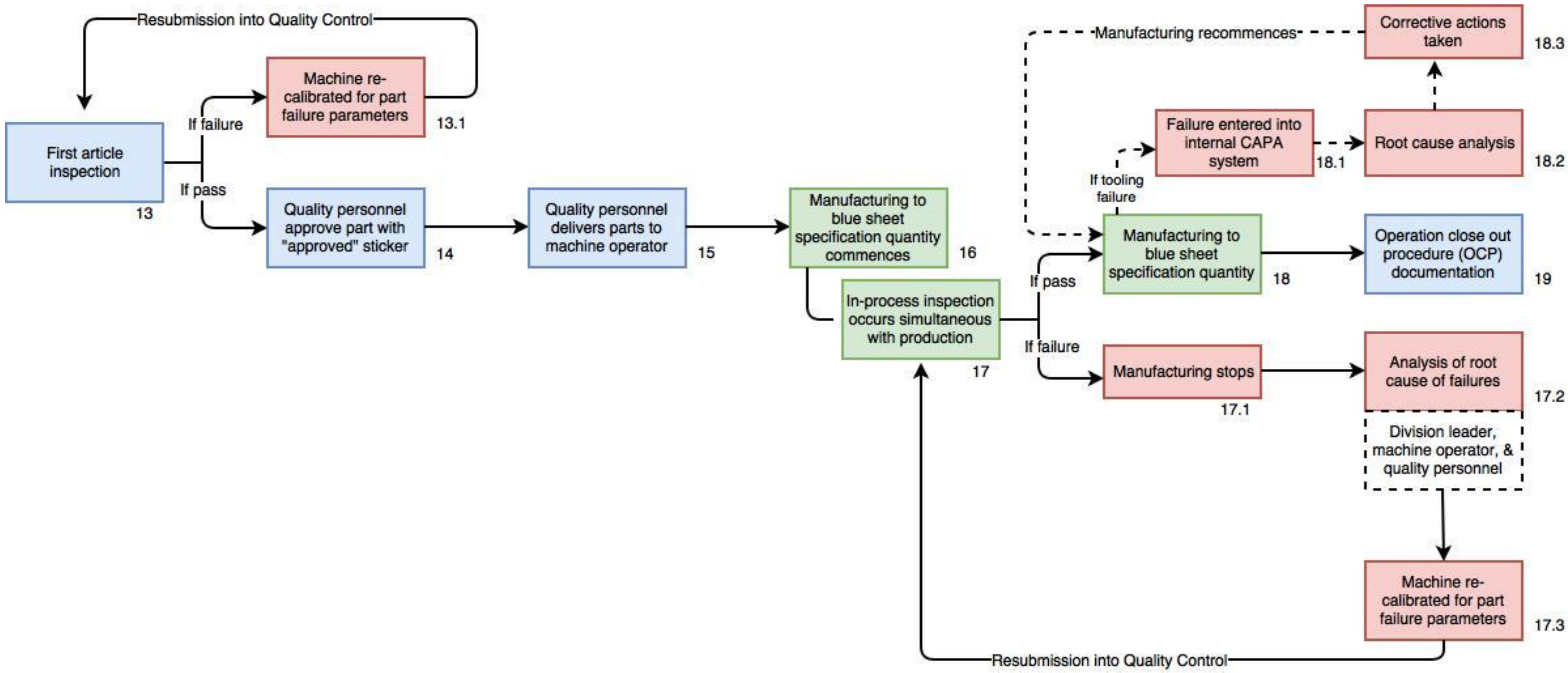


Figure 7.4: Current condition of FMC's Operation 80 – Mori manufacturing process (*Part four*)

Muda: 24 → 54%
Auxiliary work: 14 → 32%
Value-added: 6 → 14%
Total steps: 44

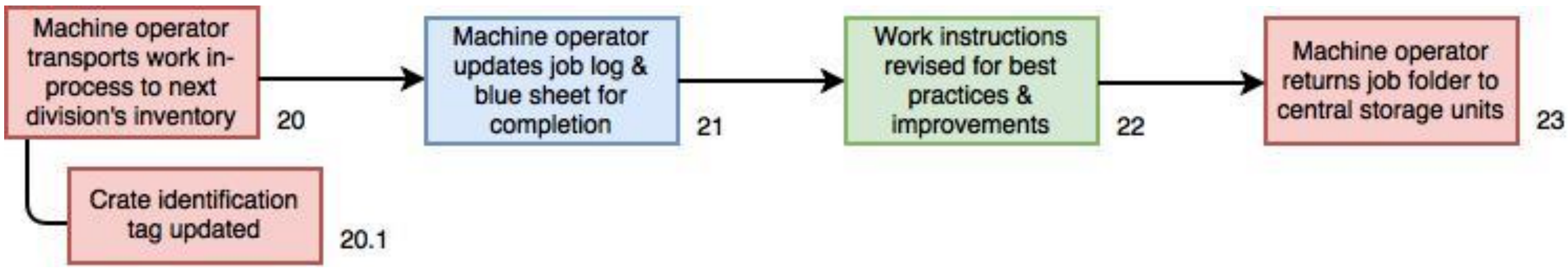


Figure 8: Comparison of current condition with proposed condition of FMC's Operation 80 – Mori machine setup process

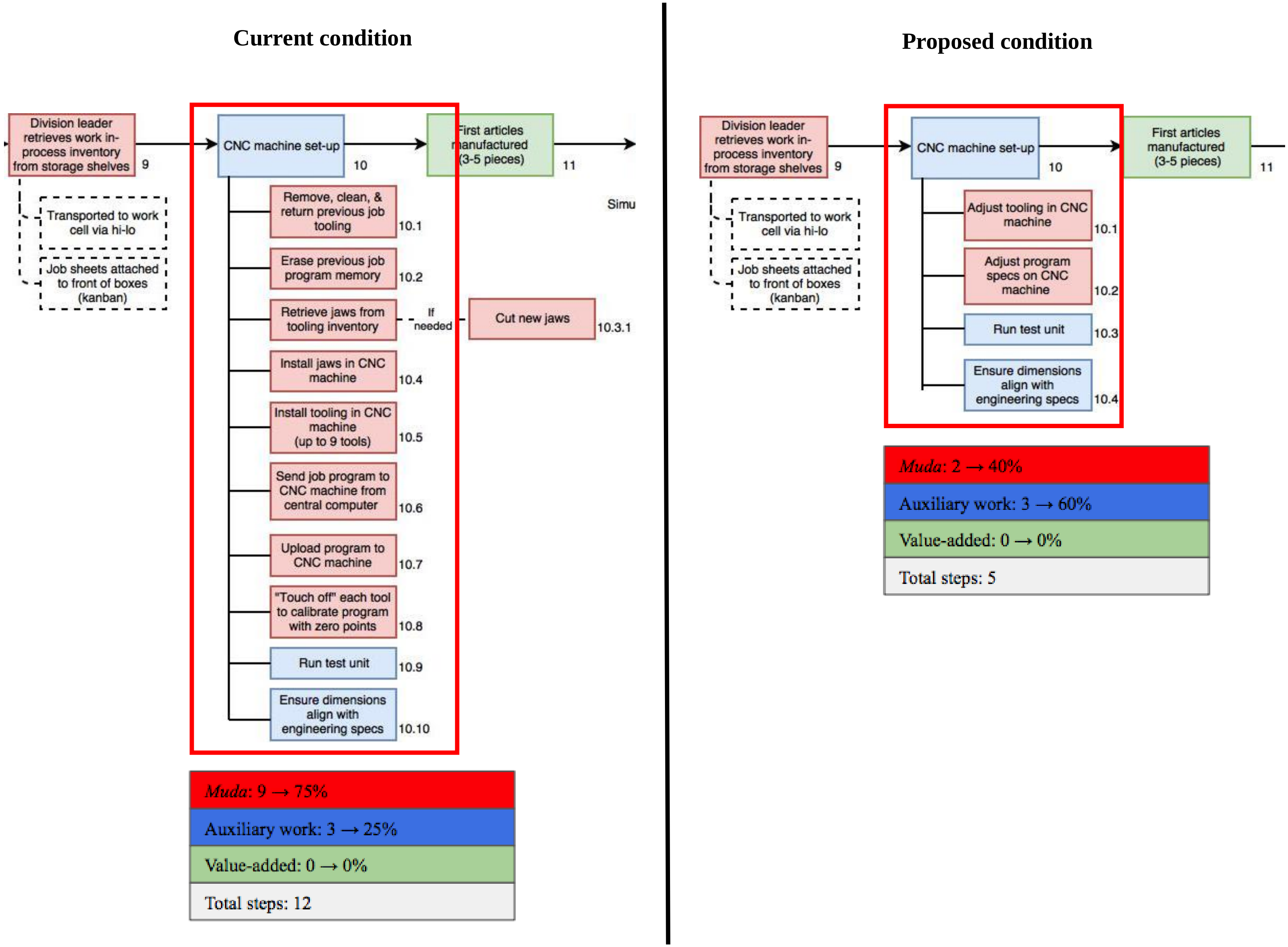


Figure 9: Ishikawa diagram of FMC's lead time reduction for slip-wicker manufacturing *kaizen*

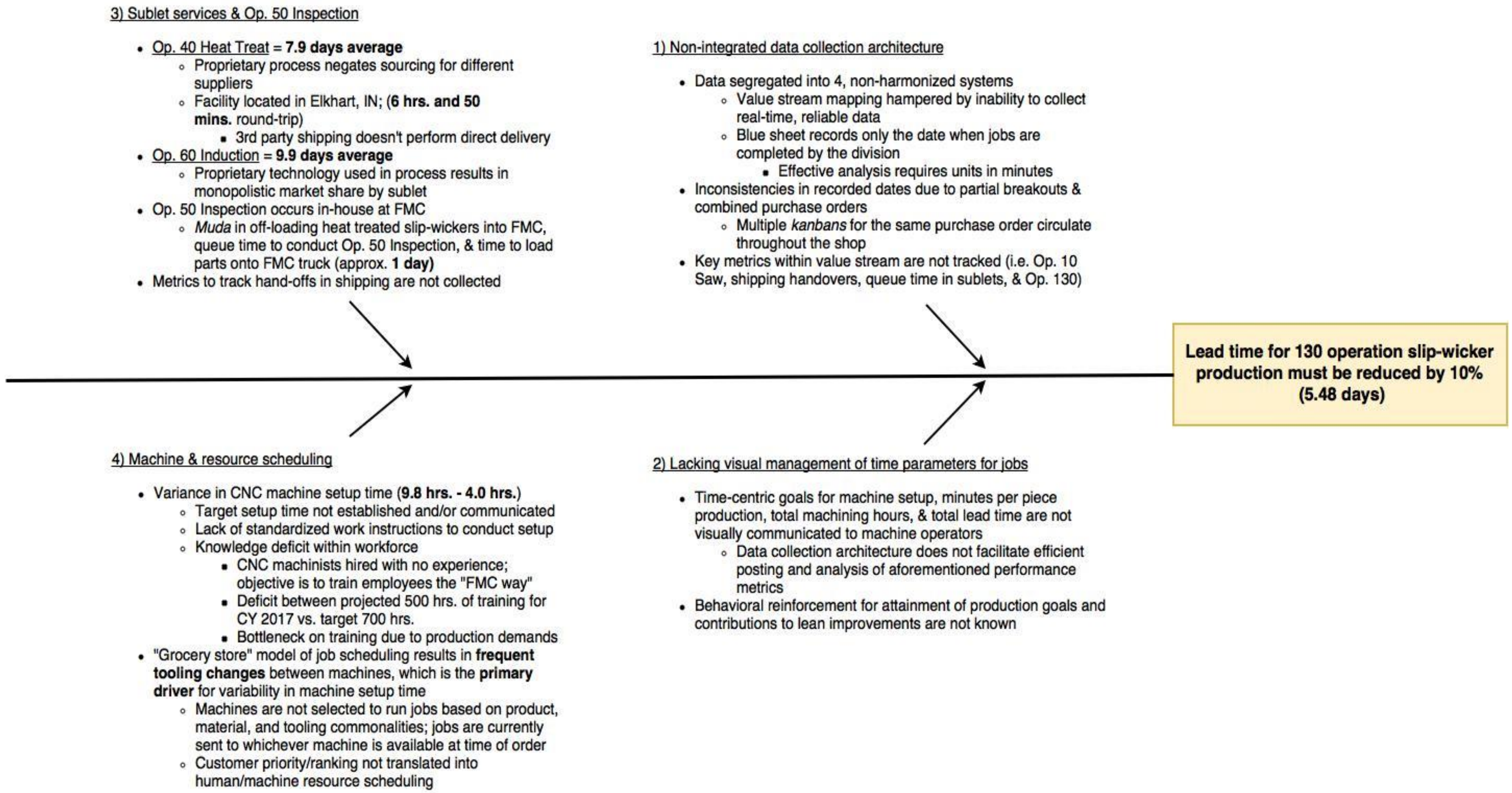


Figure 10: A3 report - Lead time reduction for slip-wicker manufacturing *kaizen*

Theme: Lead time reduction for slip-wicker manufacturing *kaizen*

To: Kevin LaComb & Carly Day, Fitzpatrick Mfg. Co.

Draft date: December 7, 2017

By: Oakland University Fitzpatrick Lean Team

Background

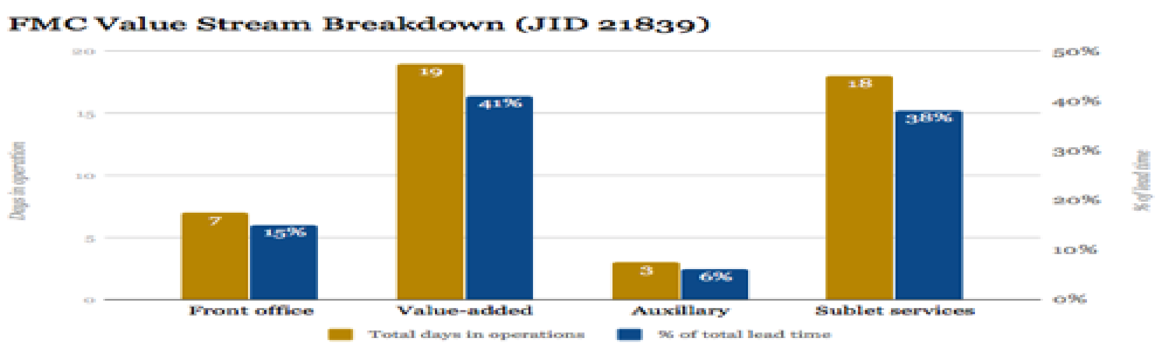
Oil & gas customer (Alpha) who comprises 12% of FMC's total operations has mandated a reduction in total lead time from **56 days** to **28 days** for the slip-wicker product. This directive was communicated 1 year ago, and continuous efforts to attain the **50% reduction** have remained the focus of FMC's management. If unable to attain the reduction, Alpha will in-source the manufacturing process within 2 years.

The production process for the slip-wicker requires 13 unique operations classified into the following categories:
1) Value-added (3 operations): Op. 20 Turning, Op. 80 Mori, & Op. 100 Milling Grinder
2) Auxillary (8 operations): Op. 10 Saw, Ops. 30, 50, 70, 90, & 110 Inspections, Op. 120 Packaging, & Op. 130 Shipping
3) Sublet services (2 operations): Op. 40 Heat Treat & Op. 60 Induction Hardening
4) Front office (0 operations)

Current Condition

Lead time

Average lead time (measured from purchase order creation to final shipment) is **54.8 days** based on 8 samples of slip-wicker jobs occurring between 8/23/2016 & 7/21/2017.
- Average lead time is **48.5%** greater than customer-mandated lead time of **28 days.**



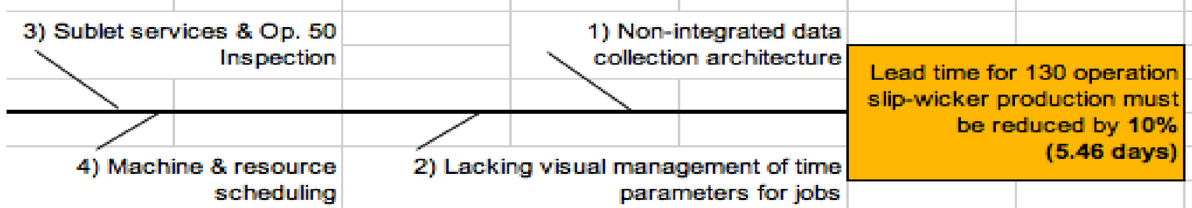
Data collection architecture

Data collection to track the flow of jobs is segregated into four, non-integrated systems: (1) job list database, (2) cost data sheets, (3) quality inspection database, (4) blue sheet (primary *kanban*).

Targets & Objectives

1) Reduce lead time on 130 op. slip-wicker jobs by **10%** of the 54.8 day average, which equates to **5.48 days.**
2) Integrate data into single database to record all hand-off points between operations.
3) Implement visual management to communicate time-centric performance objectives for slip-wicker production.

Root Cause Analysis



*** Refer to attached document for full diagram**

Target Condition

1) Standardized data collection within centralized database; current architecture (Microsoft Access Job List Database) is capable of managing recommended requirements.
   - Metrics to track: Entry & exit times per operation (accounting for split orders), machine setup, minutes per piece production, total machining hours, hand-off points in sublet shipping process (i.e. truck loading time, truck unloading time, actual delivery time, & queue times at sublets), & shipping time to final customers.
   - Record times down to minutes accuracy.
2) Visual management of lead time targets within slip-wicker value streams.
   - Metrics to post: (1) machine setup, (2) minutes per piece production, (3) total machining hours, & (4) lead time.
   - Metrics reviewed by division leader with all machine operators once per week to identify success / failure.
3) Implement self-managed, shipping pilot program using the current box truck for shipments of slip-wickers to Op. 40 Heat Treat and to Op. 60 Induction
   - Predicted time reduction (conservative): 1.00 day = 1.82% total reduction on lead time
4) Transition job scheduling & machine selection from the "grocery store" methodology to customer-centric, value streams based on part specifications, tooling, & material commonalities to reduce machine setup time.
   - Predicted time reduction: 2.95 days in Op. 80 Mori based on 1,000 part job = 5.38% total reduction on lead time

Implementation Plan

1) Data collection: Carly Day (R) --> Immediate implementation (0-2 mths.)
a) Convert documentation of job entry & operation close out to database with timestamp functionality.
  i) Initial implementation can be electronic data entry → future efforts can be a barcode scan system.
b) Begin recording metrics for all hand off points in shipping process.
b) Integrate machine cost data sheets and quality inspection logs into centralized database.
c) Create program architecture to populate data into VSM format for analysis.

2) Visual management: Kevin LaComb (R) --> Immediate implementation (0-2 mths.)
a) Define time-centric goals for machine setup, minutes per piece production, total machining hours, & lead time.
b) Communicate goals by posting targets & historical performance data on communication boards per each division.
c) Evaluate employee attainment of production goals as part of the performance management system.

3) Self-shipping pilot program: Jim Silva (R) --> Short-term implementation (2-6 mths.)
a) Begin recording metrics for all hand off points in shipping process.
b) Initiate pilot program using one designated FMC truck for sublet transportation on a one-job basis.
c) Convert Op. 50 Inspection A from in-house to mobile process before shipment to Op. 60 Induction.
  i) Train drivers on what measurements to record and how to calculate counts based on weight.
  ii) Purchase new equipment for portable hardness tester & pallet jack with weight sensor.

4) Customer-based value streams: Kevin LaComb (R) --> Long-term implementation (6-12 mths.)
a) Determine current consumption of in-house machining hours & expected profit from each customer.
  i) Categorize customers into a 3-tier schedule based on consumption of total machine hours of machining & expected profit.
b) Designate tier-1 & tier-2 customers value streams (i.e. designated employees, machines, & tooling) within manufacturing divisions.
  i) Assign work to customer value streams based on part specifications, tooling, & material commonalities.

Cost

1) Self-shipping: Pallet jack w/scale (~$800); portable hardness tester (~$600); transportation costs (mileage & fuel).
2) Value streams: Down time between shutdown for reorganization of machine cells & tooling; may cause several delay costs but in the long run should yield reduced lead time & less cost once implemented.

Follow-up

Metrics won't be accurate unless monitored on a weekly basis to ensure employees are documenting data. Once metrics are in place, analyze impact of shipping pilot, value-streams, & visual management on lead time.

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