Breaking the Mold on Job Shops

by

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Abstract

Job shops lack disciplined manufacturing strategy and execution. High variation of work results in high levels of WIP, unbalanced loads, poor shop floor visibility, underutilized machinery, and ultimately poor on time delivery, high costs, long lead times, and poor quality. To break the mold on mediocrity, job shops must build a strong foundation from which the company can grow, synchronize operations, and build the factory of the future. The research outlines the key initiatives and tools necessary for a job shop to execute this strategy and achieve operational excellence.

The strategy is explored through the lens of Company X, a CNC machining supplier serving the aerospace and defense industry. Execution to this strategy introduced a strong culture of continuous improvement and bias for action. Initial results include an improvement in on-time delivery performance at Company X from 50% to 96%. The on-time delivery performance led booked orders to hit record levels, during a global pandemic. Company X is now better positioned to execute the strategic initiatives to sustain on time delivery performance and achieve decreased costs, increased quality, and shortened lead times. Company X will break the mold on job shops and become the industry standard supplier for aerospace and defense.

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Chapter 1

1 Introduction

1.1 Project Origin and Statement of Need

Company X is a job shop in the Aerospace and Defense industry. The company was purchased by a private equity firm just before the onset of this research. In order to achieve growth targets, the company needed to break out of mediocrity and reinforce operational excellence.

Company X is one of many job shops that has unrealized potential. Job shops have a reputation for high costs, long lead times, mediocre quality, and poor on time delivery. While high volume production environments have proven strategies and tools to drive value through scale, job shops lack scale and are unable to reap the same benefits. Job shops are plagued with high levels of variation that arise with high-mix, low-volume custom parts manufacturing. As a result, job shops have failed to innovate and improve. Job shops need a playbook for leveraging specific tools in highly variable environment and a framework that ties strategy to execution to introduce meaningful improvements.

1.2 Project Goals

The goal of this research is to develop an operational excellence framework and execute a corresponding program that will "break the mold" on job shops. Through the research, a process that job shops can use to improve operations and drive value for their customers is proposed. The framework applies specifically to high-mix low volume environments. It breaks down the operational strategy into three phases, each containing several initiatives that are tailored to the job shop environment. Each initiative will outline how to apply tools from high volume environments to low-volume, high-mix environments. The research will specify the key to success now and in the future, and a framework that empowers job shops to break through years of underperformance.

1.3 Project Approach

The first step of the approach for this project is to align on the strategy and execution functions. These define what the company is going to do and how they are going to do it. For the strategy, the team will look at the ways the company can create value for its stakeholders. The company and its stakeholders orient on industry trends, new technologies, and company specific strengths. For the execution function, a proven framework is applied that supports the development of key behaviors that enable a culture of continuous improvement.

The second step is to secure the foundation, moving to stable operations from which the company can grow. This starts with an analysis of the current state of operations. Once the existing state is understood, action is taken to close any gaps between customer needs and current performance.

The third step is to focus on synchronization of operations. This is where the team will apply several lean concepts tailored to the job shop environment. The team builds on the foundation to create alignment across material flows, people flows, and information flows. They will empower the shop floor through new systems that enable consistent strong performance.

The fourth and final step of the approach is to leverage technology to build the factory of the future. Technology, when applied correctly, will support the creation of meaningful and enjoyable jobs, leaving the mundane or frustrating tasks for the technology to solve. It will enable the company to achieve efficiency and adaptability that was once considered unattainable. The company will accelerate past their competition and create unparalleled value for their stakeholders.

1.4 Thesis Overview

This thesis is organized as follows: Chapter 2 provides a background on the industry and the company that was evaluated in the scope of this work. Chapter 3 is a review of existing academic research on the relevant topics. Chapter 4 outlines the approach to strategy and execution, and introduces the strategy chosen by Company X and the execution function leveraged to deploy that strategy. Chapters 5, 6, and 7 detail the methods used in the 3 phases of the strategy, and explore the initiatives most applicable to strengthening foundation, synchronizing operations, and leveraging technology to build the factory of the future. Chapter 8 summarizes the initial results of Company X's application. Because this research was conducted during the COVID-19 pandemic, Chapter 9 details the actions taken to respond to and accelerate through a crisis. Finally, Chapter 10 summarizes the key elements of the thesis and explains the implications for similar organizations.

Chapter 2

2 Industry and Company Overview

This section provides a background on the aerospace and defense industry, followed by a background on Company X, the company where the research was conducted.

2.1 Industry Background

The Aerospace and Defense (A&D) Supply chain is comprised of several tiers. At the top are a set of original equipment manufacturers (OEMs). These OEMs include Boeing, Airbus, Lockheed Martin, and other big names. The OEMs are responsible for the integration and final assembly of the aircraft. Tier 1 suppliers, including companies such as General Electric, Honeywell, and United Technologies, manage a certified supply chain. They are responsible for designing and building systems that will be used by the OEM. OEMs and Tier 1 suppliers are supported by their Tier 2 supply base. These companies, including Parker, Eaton, and Meggitt supply components and sub-systems to both Tier 1 companies and OEMs. The Tier 2 suppliers provide design and manufacturing services, and are focused on expanding their product to new and existing platforms through improved design, higher quality, more predictable delivery, and lower costs. Tier 3 and 4 suppliers manufacture components and subassemblies that are used by OEMs, Tier 1, and Tier 2 suppliers. They provide manufacturing services to their customers, with a strong emphasis on quality and on-time delivery.

The Tier 3/4 supply base is highly fragmented. It is comprised of thousands of small job shops, most of which have less than $100 million in annual revenue and are located throughout the US, often near major OEMs, Tier 1 or Tier 2 suppliers. The job shops have been protected from foreign competition due to the highly variable, low volume, high precision, and confidential or protected nature of work.

The lack of competitive pressure combined with the capital-constrained environment that many of the suppliers operate in have contributed to the industry’s quality issues, long lead times, unreliable deliveries, and high manufacturing costs.

The poor performance in A&D supply impacts everything from design development, planning, part procurement, manufacturing and assembly, product sales, OEM product reliability and performance, as well as and aftermarket work. Inventory levels continue to increase throughout the supply chain to address the uncertainty and lack of predictability in part quality, lead time, on time delivery, and cost. Furthermore, due to the complexity of the supply chain, a small disruption caused by one supplier can cause order cancellations, cost overruns, and other major consequences for customers.

During the time period in which this research was conducted, two major events took place that impacted the industry. First, the Boeing 737 Max crashes resulted in a halt of production lines, grounding of the fleet, and cancellation of orders. To complicate things further, in early 2020, the COVID-19 pandemic wreaked havoc over the commercial aerospace industry; as commercial air travel dropped by over 70%, the industry grounded most of its fleet and cancelled orders. The bullwhip effect caused and will continue to cause massive shocks in demand throughout the supply chain, driving some suppliers out of business and forcing other suppliers to find ways to become more resilient. Several suppliers with high concentration of business with a single customer, or in strictly in commercial aerospace, were ill-prepared to adapt and have already closed their doors. It is hypothesized that several others will look to transition to other sectors to drive demand, specifically in the defense space.

Suppliers who deliver high quality products to their customers in a predictable and timely manner will weather the uncertainty that has plagued the industry. Suppliers must transform operations to become more adaptable and resilient. The companies that achieve operational excellence such that they provide the highest value for their customers at the lowest cost will outperform competition, and sustain long term performance.

2.2 Company Overview

Company X is a Tier 2 and 3 precision machining supplier that serves the A&D industry. The company was founded in 1979 by two brothers. Over the past 40 years, the brothers grew the business to over 100 employees, and they achieved this growth through their commitment to quality and customer service.

Company X prides themselves on their ability to machine the industry's most complex parts with 100% quality. As the company exceeded customer expectations in quality, and historically in delivery, price, and lead time, they received more work. The company responded to the increased demand through investments in additional space, manpower, and machinery. By 2019, the company had over 100 employees and 30 machines, processing over 200 different custom components at any given time.

At the end of 2019, Company X was acquired by a Private Equity firm. The Private Equity firm brought on a new CEO and CFO. Together, with the original owners, the team focused on driving continued growth by capturing additional customer demand and improving profitability.

Company X continued to perform over the course of increasing growth, however every new customer order added operational complexity. Firefighting, or focusing on issues that demand immediate attention, became part of the production teams' job description. Operations were quickly constrained by space, manpower, and machinery. Just before the new leadership joined the company in 2019, the team started to fall behind on deliveries. To support continued growth, the team needed to immediately address the company's declining on-time-delivery performance, and develop the long-term strategy to achieve financial and operational targets.

Additionally, Company X had a high concentration of business with a few key customers. While Company X saw growth with these customers as a result of industry tailwinds from large defense budgets and an increase in commercial air travel over the past several years, the recent events, including the Boeing 737 Max crash and the COVID-19 pandemic, made it clear to its stakeholders that Company X needed to diversify their customer base. To do this, Company X needed to achieve superior performance to attract and maintain demand from a variety of customers.

Company X needed to transform their operations to become more adaptable and resilient in the face of increased competition and uncertainty in demand.

Chapter 3

3 Literature Review

This section explores academic research related to operational strategy execution in highly variable environments. First, existing research in the into the job shop environment is investigated. Next, Lean Manufacturing, Industry 4.0, and other operations concepts are reviewed for their applicability to the high-mix, low-volume environment. Finally, proven techniques for strategy development and execution are explored.

3.1 The Job Shop

3.1.1 Job Shop Background

The Job Shop is a manufacturing site where small quantities of custom products are produced. Historically, job shops have struggled to achieve operational excellence due to the bespoke nature of work.

In an article on Job Shop Reform (Ashton & Cook, 1989) it is argued that it is time to end the mediocre quality, excessive lead times, unreliable delivery, and high costs associated with job shop manufacturing. As manufacturing entities that produce unique products for their customers, job shops experience significant variability in product mix and quantity. The highly complex and variable operating environment is the reason that job shops have been slow to reform. The products lack mass market potential, which has sheltered US job shops from foreign competition. Without competition, operational mediocrity was often accepted by management. Management is easily overwhelmed with constantly changing demands and an ongoing need to reschedule or make changes to production.

Ashton and Cook propose the following steps to job shop reformation: Make quality mandatory, get on schedule, don't sacrifice investment in capacity for immediate cost savings, improve responsiveness of outside vendors, and make performance visible (Ashton & Cook, 1989).

3.1.2 Job Shop Scheduling

One of the key areas that impacts job shop reform is scheduling. Scheduling in the job shop is exceptionally difficult because there are several objectives to satisfy. Common objectives include meeting the due dates, minimizing lead times, minimizing setup time or cost, minimizing work-in-process (WIP) inventory, and maximizing machine utilization.

In their book, *Operations Management: Concepts, Methods, and Strategies*, Vonderembse and White (2004) outline similar objectives for job shop scheduling, but note that it is usually impossible to satisfy all the objectives at one time. Therefore, the job shop must consider several tradeoffs when scheduling. For example, guaranteeing product for a customer when they want it will drive higher levels of inventory and excess capacity when demand is low. This type of process can cause cascades of interconnected issues that must be considered in planning. If the shop tries to minimize flow time, they must reduce setup time and speed up production, which requires having excess capacity. If the shop tries to minimize WIP, they will incur higher machine or employee idle time. If the shop tries to minimize employee idle time, they will need to maximize machine utilization, increase inventory, limit the orders they accept, or reduce capacity. If employee idle time is minimized, the shop runs the risk of having an overworked and frustrated workforce, which will lead to increased turnover. As you can see, it is exceptionally difficult to balance the objectives, and it is easy for a shop to fall into a reinforcing loop that decreases customer service, and sales, while at the same time increasing costs (Vonderembse & White, 2004).

The optimal scheduling of the shop, looking to provide a solution to address the complex tradeoffs that management must consider daily, is known in operations research and computer science as "the job shop problem". This problem has been widely researched because of its applications in operations research and computer science. It has been deemed an NP hard problem, in which a solution cannot be found in polynomial time.

Dr. Stanley Gershwin found that, when approaching the scheduling problem using detailed calculations like those required for an NP hard optimization problem, there are several dangers that must be considered. First, there is no obvious way to incorporate the randomness present in the real world into a mixed integer linear program model. Second, it is often impossible to develop intuition around a complex solution (Gershwin, 2016).

Techniques other than optimization can be used to simplify the scheduling process, address tradeoffs, and meet the objectives of the shop, specifically backwards scheduling. Backwards scheduling takes a job with any number of tasks and schedules those tasks in reverse order such that each task is completed just as the next task is due.

3.1.2.1 Scheduling Heuristics

In *Gaining Control: Capacity Management and Scheduling*, authors Correll and Edson (1998) proposed using backward scheduling as a simple tool to improve operations. In backwards scheduling start and finish dates for each operation are calculated by offsetting the activities from the order due date back to the necessary start date. There are several factors that play a role in effective backward scheduling including the accuracy of standard working hours, accuracy of work center routing sheets, and the capacity of the facility. In this research, the backwards scheduling techniques are applied to the high-mix, low-volume job shop environment.

3.1.2.2 Sales and Operations Planning

Sales and Operations planning (S&OP) helps companies provide better customer service, lower inventories, shorten lead times, work better with suppliers, and align internal teams. S&OP balances demand with supply. The balance helps the company plan to ensure customers get the products that they want when they want them.

The simplicity of S&OP comes from its focus on volume rather than on mix. Most organizations spend their time thinking about mix because it is often seen as most important and urgent. Volume represents the big picture, but organizations only review and set volumes once or twice a year. Teams commonly get lost in either the details or the mix, and overlook the big picture-- the volume. When a company ensures that volumes are well planned, mix is less difficult to deal with (Wallace, 2004).

S&OP connects the strategic business plans to the detailed schedules. It begins by comparing the actual performance against the plan for sales, production, on-time delivery, and backlog. This highlights deviations from what was expected, which supports improved models in the future. Next, it uses new sales forecasts to develop updated operations plans that support the company in hitting the desired performance objectives.

The two inputs to S&OP are supply and demand. Supply is determined from the available operational capacity while demand is determined from the backlog and sales pipeline. To understand the demand, it is best to look not only at your customers, but your customers' customers. The same is true for supply. Understanding what happens further down the supply chain and closer to the end customer will drive increased predictability. It will help the company stay steps ahead of their competition (Moon, 2018).

3.1.2.3 Little's Law

Little's law can be thought of as Ohm's law for queueing. Ohm's law states that the current (I) through a conductor between two points is directly proportional to the voltage (V) across the two points.

$$V = IR \qquad \textbf{(Eq. 1)}$$

The corollary for queueing is that the wait time or lead time (W) through the system is directly proportional to the WIP, or the number of items inside the system (L).

$$L = \boldsymbol{\lambda} W \qquad \textbf{(Eq. 2)}$$

$$WIP = (Throughput)\,(Lead\ Time) \qquad \textbf{(Eq. 3)}$$

In the case of circuits, resistance (**R**) is the constant of proportionality that limits the flow of current through two points. Resistance is dependent on the medium in which the current flows. In the case of queueing, lead time (**W**) is the constant of proportionality that limits the flow of material through the system. The lead time is dependent on the waste in the system. Just as using a material with low resistance in a circuit reduces the voltage required to achieve a desired current, reducing waste in a factory can reduce the lead time and increase the throughput with the same level of WIP. Here, WIP can act as a driving potential (voltage) that impacts the throughput or flow (current) of the system.

Based on discussion with Dr. John Carrier, the analogy can be expanded to consider an RC circuit, in which the system has a resistor and capacitor in series. In this case, the voltage across the circuit is the sum of the voltage across the resistor and the capacitor.

$$V = V_R + V_C \qquad \textbf{(Eq. 4)}$$

The voltage across the capacitor is equal to the charge stored (q) divided by capacitance, or the ability to store charge (C).

$$V = IR + \frac{q}{C} \qquad \textbf{(Eq. 5)}$$

Now it is possible to think of the lead time as having two components; the first being the resistance in the system due to waste that increases lead time, and the second being the capacitance in the system due to buffers that decrease lead time. The capacitors in an RC circuit act as storage bins that smooth fluctuations in voltage. In the shop, it can be thought of as features that allow for pooling of resources, such that the shop can smooth the fluctuations in WIP, and achieve shorter lead times and higher throughput.

Just as in circuits, a system with several resistors and capacitors in parallel or in series can be modeled as a circuit with a single "equivalent resistance" and "equivalent capacitance". The same is true for product in a queue. This means that it is possible to understand flow through the shop by modeling the plant as the summation of all the individual queues. The system can also be broken down on a more granular scale, looking at each individual queue to understand the dynamics at play at the machine level.

As with circuits, there is a minimum voltage to drive current through the circuit is desired. Therefore, the resistance to flow must be minimized. In the factory, this means to get the desired lead time, a minimal amount of WIP should be maintained in the system; enough to drive the system, but not so much that the lead time increases. Therefore, the greatest contributors of waste that impact the throughput must be eliminated. Just like a capacitor can be used in an electrical circuit to moderate the voltage, buffers can be used in the factory to moderate the WIP. Finally, Little's Law can be applied at the both the system level and the individual machine level to get a high-level view of the shop, and a view at more granular dynamics of specific machines or processes.

3.2 Lean Manufacturing

3.2.1 Lean Background

Edwards Deming, known as a godfather of lean developed quality-centered concepts that are the foundation for lean. These concepts were adopted by Taiichi Ohno, who led the development of the Toyota Production System (TPS). According to Deming (1982), quality is key to achieving business success and increasing the number of jobs to society.

Deming's work was extended by Ohno, who is credited for the creation of the Toyota Production System. Ohno (1988) focused on elimination of waste to increase value for customers. When asked "What is Toyota doing now?", Ohno answered, "All we are doing is looking at the timeline from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the non-value-add wastes". Ohno identified non-value add wastes as the following: defects, over-production, waiting, non-utilized talent, transportation, inventory overstocking, motion, and excess processing.

Through the relentless elimination of waste at Toyota, Ohno created a just-in-time (JIT) manufacturing system where the components and materials are delivered immediately before they are required, reducing inventory and WIP. The JIT manufacturing system involves highly coordinated production. Ohno used a pull system where new work was only started when there was demand. He created a Kanban system to limit work in progress and standard work to drive manufacturing predictability around quality and process time. In addition, the team introduced tools to immediately highlight any defects, so that they could be fixed closest to the source to both downtime and scrapped products.

The mechanisms used in TPS and Lean Manufacturing have been proven to be successful in the context of low mix, high volume environments, however they pose some challenges in a high-mix, low-volume environment. Researchers Horbal, Kagan, and Koch (2008) noted that it is difficult to develop pull mechanisms and create single piece flow when there is significant variation in the products that need to be produced. Many job shops do not have visibility into potential upcoming demand given the bespoke nature of work. This makes it difficult to determine a Takt time, or the production rate equal to the rate of the customers' demand. This in turn makes it difficult to efficiently allocate production through the factory. Instead of applying all elements of Lean to the dynamic and complex job shop environment, this research focuses on the techniques that will help to synchronize production and drive value through the continuous removal of non-value add waste. The next sections of this review focus on research associated to implementation of Lean, and the creation of a culture of continuous improvement in the section on Strategy Execution.

3.2.2 Process Improvement Tools

Taiichi Ohno had a simple approach to improvement: reduce the product lead time through the relentless elimination of non-value add waste. Reduction in the overall lead time proves to provide immense value in manufacturing. In *Building Intuition: Insights from Basic Operations Management Models and Principles*, Dr. John Little and Dr. Steven Graves (2008) write that Little's Law has played an increasingly important role in operations management. Little's Law shows that as lead time increases, the Work in Progress (WIP) increases proportionally. Decreased lead time provides increased value to the customer. Decreased lead times can be achieved through increased throughput or decreased WIP. Increasing throughput often requires additional capacity which can be costly to achieve. However, reducing the amount of WIP in the plant at a given time can be achieved without adding machines or work hours, and will result in simplified production and decreased costs. The tools described in this section support lead time reduction.

3.2.2.1 Quality at Source

Deming highlighted the importance of quality through the "Deming Chain Reaction" shown in Figure 2 (Deming, 1982). Building in quality results in less rework, better use of machines and materials, which decreases the lead time.

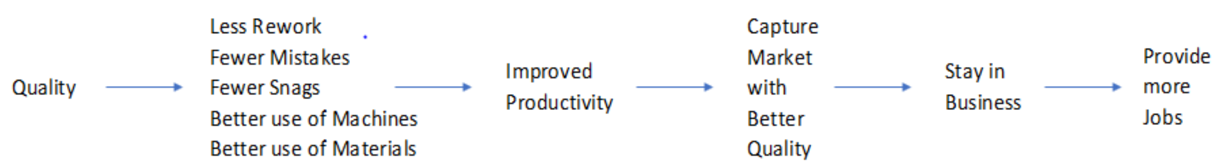

Figure 1: The Deming Chain Reaction highlighting the positive impact of quality on business performance

Taiichi Ohno saw the importance of Deming's work. At Toyota, mistakes are corrected immediately. Ohno (1988) notes "To rush and not take time to correct a problem causes work loss later" . If a quality issue is not corrected at the source, the defective part will continue to be processed. This causes several problems. First, value is added to the part as it is processed. If the part needs to be discarded due to the defect, it becomes more costly with each additional production step. If the part does not need to be discarded, it will need rework. The rework becomes more time and labor intensive as additional value is added to the part. Next, if the failure is not addressed immediately, it is possible that several other parts are produced with defects. Finally, the root cause of the defect will be harder to identify. To support the quality at source, Toyota used standardized work.

3.2.2.2 Standardized Work

Standardized work provides employees with instructions to make quality products in the safest most effective way. The power of standardized work is seen in Formula 1 Racing. In a matter of seconds, the pit crew changes wheels, replaces the nose cone, and fixes punctures. Each step of the process is rigorously tested and clearly documented. The tools are organized to drive efficiency. This enables the team to get their driver back in the race in only 2 seconds.

Standard work serves as a document for the current best practice, and a baseline for improved methods. According to lean, there are three components to standard work: Takt time, work sequence, and the inventory required to keep the process operating. There are several benefits to standardized work including a decrease in variability, and an increase in flexible operations. Additionally, it serves to document tribal knowledge about processes, which will reduce defects and promote problem solving (Byrne, 2012).

When developing standard work, it is critical to remember that the people doing the work need to be involved. Documents used for standard work should be made in a format that is simple. The standard work should be audited on a regular basis, and updates should be simple so that the team is incentivized to document process improvements, rather than work outside of the standard.

In a high mix environment, it can be difficult to develop standard work for every unique part. However, there are processes that are not part-specific that should be standardized. This involves looking for similarities in parts and grouping them together. For example, a vehicle at a Toyota plant may have several different paint color options, but the process to paint the car will be the same.

3.2.2.3 Setup Reduction

Taiichi Ohno (1988) noted that setups are an element of production that increases cost and reduces efficiency. Art Byrne (2012) argued that setup reduction is core to Lean, noting that

“One of the first goals is to cut your setup times”. The number of setups required increases with the variety of parts being produced. While setups are a necessary waste, they are exceptionally costly. The most common limiting factor for production is machine and manpower availability, and setups consume both resources.

Job shops frequently resort to batching production to reduce total setup time throughout the shop. The increased batch sizes, however, increase WIP and inventory. From Little’s Law, increased WIP will increase the lead time. Therefore, batching may reduce the total setup time, but it does not benefit the overall lead time.

Shingo (1996) introduced a solution to long setups through the Single Minute Exchange of Dies (SMED) in his book, A Revolution in Manufacturing. The Single Minute Exchange of Dies is summarized in a 3-step process. First, each process of the setup is defined as internal or external, and standardized. Internal processes are defined as processes that can only be done while the machine is stopped. This includes tool changeovers or updating CNC programs on the machine. External processes can be done when the machine is running, and should therefore be completed while the previous job is running. Through the definition of processes and standardization there is often a 30-50% reduction in setup time. Next, the internal processes are reviewed, looking for ways to convert the internal process to an external process. Once the conversion is complete and the internal can become an external process, the machinist can complete that portion of the setup while another part is running. Finally, each process will be reevaluated on a continual basis to develop more efficient standardized ways to do each setup process. SMED is a solution that helps a company reduce overall setup time without the use of batching. This reduces the overall lead time and provides flexibility to meet highly variable demand.

3.2.2.4 Visual Controls

As a historical example, following the introduction of steam propulsion, Naval ships began traveling in proximity at high speeds. The Navy needed a way to communicate across several ships to rapidly update and align their forces on maneuvers, fighting instructions, and other tactics. Updates across a radio channel can be distracting for unaffected parties and can lead to congestion on the radio channel. Additionally, messages via radio can be misinterpreted by an ally, or picked up by an enemy. Finally, all necessary recipients of the message may not hear it over the radio. To address these challenges with communication, the Navy has adopted Naval signaling flags, a form of visual control. A sequence of flags would be placed on the flag hoist of the ship, providing surrounding ships with quick, clear, uncompromised information (Zingheim, 2018).

Visual controls have been adopted in factory settings to help teams rapidly determine when operations are progressing well, and when operations have been compromised. Visual controls help identify problems that need to be resolved, bringing to light any abnormalities or deviations from standards. People feel comfortable addressing an issue when it is made clear upfront. The team needs to understand what problem needs to be solved, and visual controls make that easy.

There are several benefits to visual controls, including reduced manufacturing costs through a reduction in WIP, higher quality, and increased safety. Visual controls ensure that communication is happing throughout the shop, without any words being said.

3.2.2.5 5S

Art Byrne (2012), the author of *The Lean Turnaround* argues that 5S is a critical step in the implementation of Lean (Byrne, 2012). 5S, also referred to as the five pillars of the visual workplace are sort, set in order, shine, standardize, and sustain. While often overlooked due to their simplicity, they have proven to increase productivity, improve quality, provide a safer working environment, and support the bottom line (Hirano, 1996).

Sort involves removing unnecessary items from each area. In this step the items, tools, and materials in the shop should be considered. The items that support work in that area should stay, while the remaining items should be removed. Set in order includes organizing and identifying storage for efficient use of the remaining items. Here, the team should find a place for items close to where they are used. Items that are not used regularly, or that are spares should be organized and placed in a central location. Shine involves cleaning and inspection on a regular basis. Machine shops are notorious for grime and dirt that builds up over time. Daily cleaning should be done by all employees to keep their workstations clear. During this process, employees will identify things that are out of place or in need of repair. Standardize is incorporating the process into standard operating procedures. During standardization, the process is written down so that employees understand the decisions made in the earlier steps, and are held accountable for incorporating the new practices. Sustain is assigning responsibility and tracking progress on the steps. 5S is not powerful when done once; it is intended to be an ongoing cycle. The steps are interdependent, for example, without implementing the sustain step, areas in the shop that had previously been cleared will fill. For 5S to be successful, it must be repeated and maintained.

3.2.2.6 Process Mapping and the Gemba

Process maps are graphical representations of the steps in a process. They show a high-level view of the process. The value in a process map is that it drives a common understanding of the process, highlighting the relationships between inputs, outputs, and key decision points. Taiichi Ohno noted that you must first make waste visible before you are able to remove it. In the same way, you must first understand a process before you can improve it (Ohno, 1988).

Process maps should be developed in collaboration with the individuals that contribute to the process. If a manager builds a process map, he or she will likely miss out on the intricacies that increase complexity, or the workarounds developed by the frontline to manage variability. Hidden factories, or the unplanned activities in the factories are often unknown to management. Research conducted by Dr. Armand Feigenbaum (1991) finds that up to 20-40% of activity in a factory is unplanned.

One of the first steps to developing a process map, and identifying the hidden factories, is to go to the Gemba which refers to the place where value is created. This means management must go out on the shop floor to shadow, thoughtfully question, and observe a process. A leader that spends time with the front-line showing interest and desire to support the team will build stronger, more trusting relationships. This will help the team bring the existing inefficiencies and workarounds to the surface, which is the first step to improvement.

Both process mapping and going to the Gemba are extremely powerful tools. They should be used to support all phases of a project. They help create a teamwork environment and help to ensure the right problems are being solved.

3.3 Industry 4.0

3.3.1 Industry 4.0 Background

Industry 4.0 originated with the German Federal Ministry of Education and Research in 2012. While there is no consensus on the definition of Industry 4.0, the most rigorous consensus by researchers Herman, Pentek, and Otto (2015) suggest that Industry 4.0 is cyber-physical systems (CPS), smart factories, and the internet of things (IoT).

CPS is defined as integrations of computation and physical processes where computers and networks monitor and control the physical processes, usually with feedback loops between the physical and computational processes (Lee, 2008). The Smart Factory is defined as a factory that is context-aware and assists people and machines in execution of their tasks. To build the Smart Factory, CPS communicate over the IoT, or the network by which CPS cooperate through unique addressing schemas to assist people and machines in the execution of tasks (Hermann et al., 2015).

Concepts and components of Industry 4.0 are referred to differently by different countries, organizations, and individuals. Common terms include Industrial Internet, Advanced Manufacturing, Integrated Industry, Smart Industry or Smart Manufacturing. There is not yet a consensus on implementation of Industry 4.0. The focus of this research is on the applications for, and the implementation of technology specifically in a high-mix low-volume manufacturing environment. The next section highlights challenges business have faced with Industry 4.0. Later, the research reviews the technology that supports the creation of a smart factory, using IoT and CPS.

3.3.2 Challenges with Industry 4.0

A study conducted by Accenture finds that only 13 percent of businesses have realized the full impact of their investment in digital transformations (Stacey et al., n.d.) suggesting that there is unmet potential in the implementation of Industry 4.0.

The issue with Industry 4.0 Implementation, is that many companies are introducing technology to improve sub-optimal process. In the article *Lean Manufacturing in a Digital World*, Jill Jusko (2020) writes that "While smart technologies may ultimately enhance the pursuit of continuous improvement, initially they could add a layer of complexity that a lean implementation may not be mature enough to handle". In the same article, she cites Dr. John Carrier, who said the greatest opportunity for Industry 4.0, "Is providing real time visibility into parts of the system that were previously invisible" . Our approach is to evaluate technologies that first create visibility, in turn enabling Company X to work on the highest value work to become the standard for aerospace and defense supply.

Looking back to Toyota, the use of Andon technology, a system that notifies management of a quality or process problem, highlights the importance of developing a synchronized culture before introducing new technology. In *The Toyota Way*, a manager at a Toyota plant is cited saying that "Andon only works when you teach your employees the importance of bringing problems to the surface so they can be quickly solved. Unless you have a problem-solving process already in place and people are following it, there's no point in spending money on fancy [Andon] technology." (Liker, 2003)

According to Herman, Pentek and Otto, Industry 4.0 is intended to support interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity. These principles align with the principles of Lean. Therefore, this research approaches the implementation of technology through the lens of Lean, taking a system-level approach and looking at how to create the greatest value for the customer. With the mutual enablement of Lean and Industry 4.0, researchers at The Boston Consulting Group finds that companies can reduce conversion costs by as much as 40%, compared to approximately 15% when technology is applied alone. (Küpper et al., 2017)

3.3.3 Technology Review

There are several technologies that are being leveraged by companies as part of their digital transformation, however as Company X typically operates in a high-mix, low-volume environment, this work solely focuses on exploring the technologies that show the most potential for high-mix manufacturing environments.

3.3.3.1 Digitization

Digitization is the process of transforming analog processes into a digital form. In the factory, this involves transitioning to digital processes using smart or connected IoT devices.

The manufacturing industry has one of the highest percentages of human error. The purpose of digitization is to reduce these human errors through increased visibility that drives improved decision making through more accurate and available data. Increased visibility is achieved because it allows information in multiple formats to intermingled and carried with the same efficiency (McQuail, 2010).

Digitization can be achieved through a variety of different means, including machine monitoring, remote monitoring, real-time status tracking, digital work instructions, and in-process quality checks. The data serves as a source of truth that can address challenges employees face, and guide improvements throughout the organization.

3.3.3.2 Digital Twins

Tao et al. (2019) argues that digital twins are one of the most promising technologies for achieving smart manufacturing. Digital twins are virtual replicas of physical systems that seamlessly integrate the digital and physical worlds. The concept of digital twins was proposed by Grieves in 2003 and revisited by NASA in 2012. The digital twin enables a team to simulate and test different decisions before time and money are spent deploying the actual devices. A digital twin can be used understand the impact of major decisions.

The digital twin consists of several dimensions: the virtual entity, the physical entity, the data, and the connection between each part. The data is the central entity of the digital twin. The virtual part supports decision making that will ultimately impact the physical part.

With a digitized workflow, sensors can be leveraged to provide real time feedback to the digital twin model, increasing frequency of updates, and improving overall accuracy of predictions.

The digital twin has been widely adopted to support design, production, and management efforts. As additional data becomes available through IoT devices, the importance and impact of the digital twin will grow. Machine learning and optimization techniques will be used to automate decision making, helping teams achieve more with less.

3.3.3.3 Automation and Robotics

Automation is the process by which technologies are used to perform tasks where human input is minimized. Robotics is the development of systems that replicate or extend human actions, often used in automation.   When implemented properly, there are several advantages to automation and robotics. These advantages are increased efficiency, safety, and quality, along with reduced error, and cost.

Automation and robotics have proven to be extremely valuable in high-volume production environments. In these environments, the same part is being produced using the same process. The company can afford to invest in part-specific solutions to automate manufacturing. The high initial cost for automation is offset by a reduction in labor expense to produce the part.

In high-mix, low-volume environments, part-specific automation is not economical. Automation is best applied in areas where scale can be realized. Because the machining of each part is unique, it is not a valuable place to spend energy or resources on automation. Instead, it is helpful to look for commonalities across all processes. Shared processes can be simplified and then automated, allowing the teams to focus on the complexities associated with each unique part.   The team can look for commonalities between features on parts to introduce automation. Consider 100 different components each containing an identical drilled hole on the part. While each part is different, the parts all have the same drilled hole. Therefore, the same process for machining that hole can be used on all parts. The team can automate the programming for the machining of that drilled feature on any new part that contains the feature.   The team can also look for commonalities between processes on parts. For example, each machined part requires cleaning. An automated washing system could be utilized because all parts need to be washed after machining.

3.3.3.4 Additive Manufacturing

Additive manufacturing is a digitally native process. It uses a computer-aided design (CAD) data to instruct hardware to deposit material in layers. The material is added, layer by layer to develop a physical version of the digital CAD model.

Additive manufacturing has several benefits when compared to the traditional subtractive manufacturing processes.   Because additive manufacturing is digitally native, the process to translate a model into instructions to build the physical object happens automatically. There are no upfront investments in fixtures or programming. The production of the part can happen immediately, reducing lead times form months to days or hours and eliminating the need to drive value through scale. Material is only added where it is needed. This can reduce costs by decreasing material consumption. Also, additive manufacturing makes it possible to produce complex geometries like undercuts or cavities that were nearly impossible to manufacture using subtractive techniques.

While additive manufacturing shows an enormous potential for manufacturing and design, there are several challenges, most notably associated with materials and processing. Additive manufacturing materials are not well understood. There is no common set of standards for additive manufacturing materials that designates performance and properties like traditional manufacturing has. Additive manufacturers must be able to qualify materials to ensure they will meet the industry standards. Furthermore, processes must be standardized to ensure the parts perform as intended during use.

3.4 Strategy and Execution Research

The key to producing results is to develop a winning strategy, and to execute on that strategy. In this section techniques for strategy development and execution are explored.

3.4.1 Strategy Background

MIT Sloan Professor Donald Sull (2017) defines strategy as a framework to guide critical choices to achieve a desired future. He writes that winning strategies are formulated from a set of choices including but not limited to who the company will serve, what the company will offer, and how the company will provide their offering to make money.   The key to an effective strategy is to develop a set of strategic priorities that are most impactful to an organization's success in the next few years.   The priorities should be limited, bridge between long-term goals and short-term objectives, address vulnerabilities, provide concrete guidance, and align the organization, and focus on the future.

There are several frameworks that support strategy development, and highlight the opportunities for a firm to create value.

SWOT (Strengths, Weaknesses, Opportunities and Threats) Analysis is one of the most widely used tools in strategy development. It is used as a framework to categorize the factors that impact the strategy (Puyt et al., 2020). It supports alignment among a firm to the organization's strengths, weaknesses, opportunities, and threats. Strengths and weaknesses are internal, encompassing the areas you have control over. Opportunities and threats are external, providing a clear picture of what is going on outside of the organization and in the overall market.

Researchers Brandenburger and Stuart (1996) propose using a value-based business strategy in which a business introduces an asymmetry between themselves and other firms by increasing the gap between customer willingness to pay and the cost of the inputs. Strengths and opportunities highlight the areas where the company can look to increase the willingness to pay, widening the gap between cost and willingness to pay, in turn creating value. Weaknesses and threats close the gap between cost and willingness to pay.

Michael Porter (2017) developed an additional framework that helps the team vet out competition beyond their established rivals, suggesting that there are four additional forces that can impact future success. These forces are: customers, suppliers, new entrants, and substitute offerings. These forces, together with established competition, help companies identify and exploit disruptive trends.

These frameworks help leadership teams understand what strategic initiatives they should focus on to create and capture value.

3.4.2 Execution Background

For a strategy to be successful, a leader must be able to execute it. In *The 4 Disciplines of Execution*, author McChesney and Covey (2016) ask, "Why is execution so difficult? After all, if the strategy is clear, and you are the leader are driving it, won't the team naturally engage to achieve it?".

Anyone that has tried to bring a group of people together to execute their plan knows that the answer is "no". McChesney and Convey state "Your biggest challenge is in getting people to execute at the level of excellence you need". They propose a set of four disciplines to translate a strategy into results.

First, the team must identify the gap and what must be done to close that gap. McChesney and Convey warn that "There will always be more good ideas than there is capacity to execute." The team must narrow in on one or two single goals. This creates alignment and focus for the organization. Every action can and should directly influence the goal. Achievements that do not directly impact the goal do not drive execution of the strategy and do not matter. What an organization chooses to not do is just as important as what they choose to do.

Second, the team must focus on the few activities that have the most influence on the goal. Vilfredo Pareto (1935), an Italian economist discovered that that 20 percent of all the people, own 80 percent of the wealth. His finding has proven to hold across several economic and management scenarios, and has been coined as the 80/20 rule. The 80/20 rule, or the Pareto Principle states that twenty percent of activities produce eighty percent of results. The team must focus on what Pareto considers the "vital few", or the "20%". These few activities have the most influence on the goal. Strategies are often stated in terms of lagging measures. Lagging measures are difficult to directly influence. Therefore, the organization must track the "vital few" using leading measures, or the levers that can be pulled to close the gap. The leading measures predict success in the lagging measure.

The third step is to create a compelling scorecard. People are more engaged when they know how well they are doing. The scorecard also creates a common language throughout the organization. It helps the team quickly see where they are winning or losing. This makes it easier for the team to adapt and adjust their activities to focus on winning.

Finally, Covey and McChesney state that "Accountability breeds response-ability". To create an agile and responsive environment, the team must introduce a cadence of accountability. They suggest that each team hold a quick weekly meeting to review successes, analyze failures, and make corrections. During the meeting, he suggests that each team member commit to one action that will influence the lead measure. At each meeting, the team follows up on the commitments from the previous week, making everyone feel accountable to the team, rather than their manager. This process fosters a culture of continuous improvement.

Chapter 4

4 Strategy and Execution in Action

This section provides an overview of how Company X applied the strategic and execution frameworks described in Section 3.4 to guide their operational transformation.

4.1 Strategy Development

Job shop leadership needs to start by answering the question, “What do we want to be when we grow up?”. The team at Company X wanted to escape mediocrity and become a leader in aerospace and defense supply. With that goal in mind, the team needed to develop a strategy that defined clear objectives and steps to achieve the goal.

To home in on the “what”, the company must first understand the market. Porter’s 5 forces is a framework that helps a team explore the market landscape.

Table 1: Summary of Company X's Porters 5 Forces Analysis

Dimension	Status	Situation
New Entrants	Positive	Higher barriers to entry due to compliance requirements. Moderate switching costs for customers.
Customers	Positive	Large customers, diverse buyer entities. Purchases represent a small but critical portion of spend. Some customers exploring backward integration
Substitutes	Neutral	New materials, new manufacturing processes are entering but not imminent threats
Suppliers	Neutral	Diverse set of suppliers for machinery, materials, and processing that are not specialized for just this market. This market space is not important to them.
Competition	Positive	Fragmented network of machine shops and in-house suppliers

Porters 5 forces suggests that there is significant opportunity for value creation at Company X. However, Company X had to be aware customers bringing manufacturing capabilities in house, suppliers gaining power, changes in product offerings through new manufacturing processes like additive manufacturing, and consolidation of competitors.

The SWOT analysis clarified the company's strengths, weaknesses, opportunities, and threats. It highlights where Company X had been, and the core competencies that led the company to strong growth over four decades. It sheds light on the areas Company X needed to improve on to maintain growth and become the industry standard.

Table 2 Summary of Company X's SWOT Analysis

Strengths	Weaknesses	Opportunities	Threats
Quality Performance	On-time Delivery Performance	New Platforms	Additive Manufacturing
Established Customer Relationships	Lack of IP	Diversify Customer Base	Customer in-house capabilities
Growing Platforms	Concentrated with a few Customers	Integrate manufacturing processes	Market pricing pressure
	Long lead times	Long term agreements	Consolidation of competition

The SWOT analysis showed that Company X should continue to play to their strength of exceptional quality performance. However, it also highlighted that on-time delivery required immediate attention. External to the company, the SWOT analysis reiterated what was shown through the Porter's 5 Forces analysis. The company needed to be aware of vertical integration of manufacturing capabilities at their customers, consolidation of the competition, and potential loss of business to additive manufacturing. Company X needed to focus on creating and capturing value from their customers.

The SWOT and Porter's 5 Forces analysis showed that cost, lead time, quality, and on time delivery are the key value drivers for Company X. If Company X was competitive on the key value drives, they could increase demand and fight off the threats of additive, backwards integration, and consolidation of competition. The figure below summarizes where Company X stood at the beginning of the research relative to the industry's position. From this figure, the gap between Company X and the industry, and the opportunity for Company X to create and capture value is shown. The figure helped the management team identify where they needed to focus so that they could become a leader in Aerospace and Defense Supply.

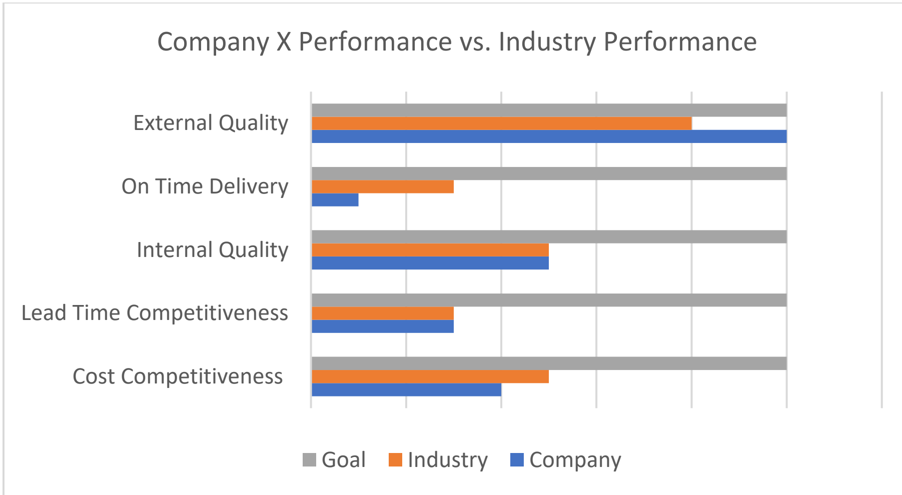

Figure 2: Company X's performance on key value drivers relative to the industry and their internal goal based on the management assessment of performance relative to competitors

What stands out is that Company X has very strong external quality. The company met their quality goal and exceed the quality performance of their competition. In contrast, Company X did not meet the goal or the industry standard for on-time delivery performance. The company had a significant gap that needed to be closed.

The systems diagram in Figure X shows the impact that delivery performance has on customer demand. An increase in delivery performance results in increased demand. With demand, Company X will have increased revenue. As revenue increases, it becomes easier to justify the continued investment in improvement initiatives. This will propel quality and lead time improvements, which will in turn address the gap seen between Company X and the industry in Internal Quality and Lead time competitiveness. The shortened lead times and improved quality will drive cost competitiveness, reinforcing customer demand. The opposite is true if delivery performance suffers. Therefore, it was critical for Company X to improve delivery performance immediately.

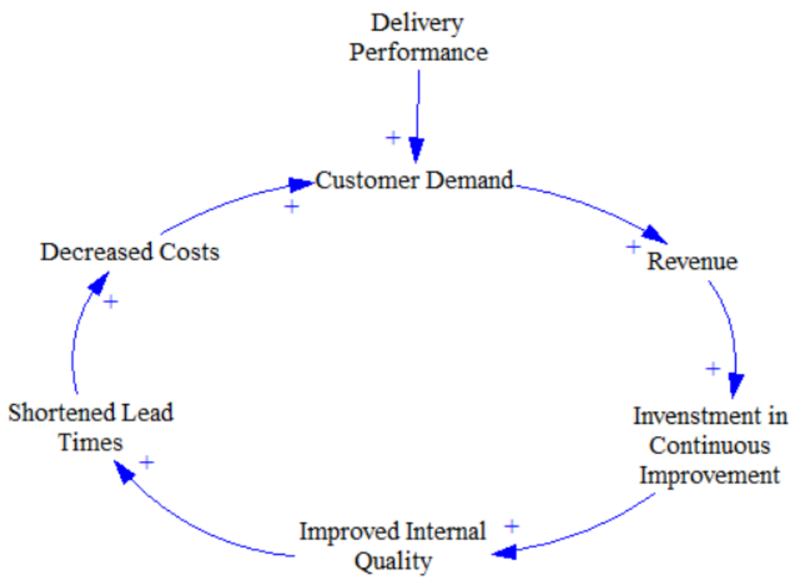

Figure 3: The Delivery Performance reinforcing loop on Customer demand

Figure 5 summarizes the phases of Company X's strategy. It is focused on creation of value in the areas highlighted above. It builds on a set of tools that are described in later sections that support the Company value creation mission. The first step for Company X is to remove roadblocks that stand in the way of improvement, and immediately address on-time delivery as part of strengthening the Company's foundation. The next step is to develop improved capacity planning and scheduling tools, reduce setup times, and enable flow as part of synchronizing operations. Once operations are synchronized, final step for Company X is to digitize workflow, adopt and compete with additive manufacturing, and automate production to build the factory of the future.

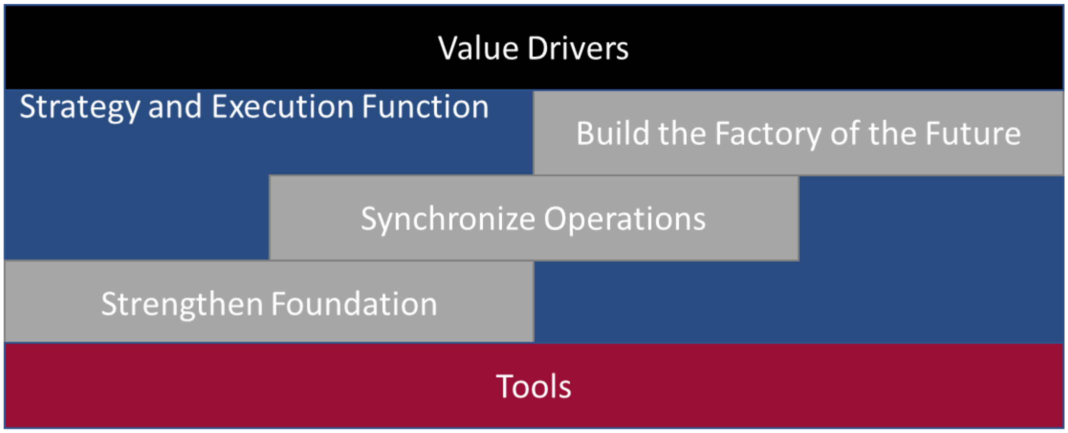

Figure 4: The operational excellence strategy framework developed for Job Shops. There are three phases of the operational excellence strategy. The strategy and execution functions span each phase and represent what the company will do and how the company will do it respectively. The strategy is built on a set of tools that the company will use to execute each phase. The value drivers guide the initiatives in each phase of the strategy.

Table 3 summarizes each phase of the strategy, and the key value drivers that will be impacted through the execution of the strategy. The Strengthen Foundation phase initially focuses on on-time delivery improvements, closing the gap between Company X and the competition while pushing towards the goal of perfect on-time delivery. Once customers receive the already high-quality product on-time, the organization can synchronize operations to improves lead times and internal quality. The lead time and quality improvements will support cost competitiveness, which will be a key initiative as Company X works towards its goal of building the factory of the future.

Table 3: Summary of the key value drivers and corresponding strategic phase in the operational excellence framework. A full dot suggests that the initiatives in the phase of the operational excellence framework will support the corresponding value driver. A fractional dot suggests that a portion - the fraction of the dot that is filled - of initiatives in the strategic phase will support the corresponding value driver.

	Current State	Strengthen Foundation	Synchronize Operations	Build Factory of the Future
Cost			◔	●
Lead Time			◕	●
Internal Quality			●	●
OTD		●	●	Maintain
External Quality	●	Maintain	Maintain	Maintain

Due to the nature of the company and the limitations of current implementation practices each phase of the strategy takes a combined approach by leveraging tools from Lean, Industry 4.0, and other operations best practices. Lean is an infrastructural piece for Industry 4.0. The nature of the issues that must be improved immediately, including on-time delivery, internal quality, and lead time are best addressed by lean, demand planning, and other operational best practices. Company X plans to do this in the first two phases of the strategy which are strengthening foundation and synchronizing operations. Industry 4.0 tools can then be used to extend the improvements and drive cost competitiveness in building the factory of the future. The table below summarizes the tools used in each phase of the strategy.

Table 4: Summary of the tools and corresponding strategic phase used to implement each initiative of the operational excellence strategy. For example, initiatives in the Strengthen Foundation phase will fully leverage tools including Process Map and Gemba Walks, Visual Controls, 5S, and Backwards Scheduling, and begin to use Quality at Source, Setup Time Reduction, Standardized Work, Demand Planning, and Cross Training.

	Tools												
	Lean						Other			Industry 4.0			
	Process Map and Gemba Walks	Quality at Source	Visual Controls	Setup Time Reduction	5S	Standardized Work	Demand Planning (S&OP)	Backwards Scheduling	Cross Training	Digitization	Robotics and Automation	Digital Twin	Additive Manufacturing
Build Factory of the Future	◑	◑	◑	◔	◔	◑	◑	◔	◔	●	●	●	●
Synchronize Operations	◕	◕	●	◑	◔	◑	◑	●	●	◑	◔	◔	◔
Strengthen Foundation	●	◔	●	◕	●	◑	◑	●	◔				
Current State						◔							

4.2 Execution Function

The execution function ensures accountability throughout the organization. Company X adopted an execution process that aligns with Covey's four disciplines. The purpose of the execution process is to align the team around what needs to be done, and to manage what the team has chosen to work on. The Execution function helps the team gain traction around each initiative, while instilling the behaviors in the team that make continuous improvement part of the company's core, rather than a mandate from management.

The first step is to articulate the goal that the team is working towards. Once the goal is clearly defined, the leading indicators are identified. Next, a clear scorecard is developed to indicate progress towards the goal. Finally, weekly check-ins are used to drive accountability among the team.

The execution function will be used to develop the following behaviors:

Table 5: The behaviors and the corresponding phase in the operational excellence plan where the behavior will be developed. The focus for the Strengthen Foundation phase is Communication and Collaboration, with some initiatives that will introduce a culture of Accountability and Customer Focus. When the Build the Factory of the Future phase is complete, all behaviors will be fostered which is represented by the column of filled in dots

	Description	**Strengthen Foundation**	**Synchronize Operations**	**Build Factory of the Future**
Drive	Shows passion for improvement and their job		◕	●
Curiosity	Explores and try new things; willing to experiment, fail, and adjust		◕	●
Customer Focus	Obsesses with doing what is best for the customer	◑	●	●
Accountability	Follows up on work; is reliable; takes on new work	◑	●	●
Collaboration	Asks for help; works with team to make decisions	●	●	●
Communication	Discusses concerns with team; provides updates to team	●	●	●

These behaviors foster a culture that enables continued value creation for employees, customers, and investors. In combination with the initiatives outlined in the strategy, the execution function supports a culture of continuous improvement through clear objectives, key levers to pull, helpful performance indicators, and accountability practices. Each initiative highlights the behaviors in focus. While all the behaviors are important in achieving operational excellence, collaboration and communication are pre-requisites for accountability, curiosity, customer focus, and drive. Collaboration and communication are first and foremost for the team as they strengthen the foundation. Once the team has developed a collaborative and communicative environment, accountability, curiosity, customer focus, and drive follow. These core values and principles are introduced in strengthening the foundation, fostered more fully in synchronizing operations, and then leveraged as the Factory of the Future is built within the company.

Chapter 5

5 Strengthen Foundation

The first and arguably most important part of the strategy to achieve operational excellence is to build a strong foundation. A strong foundation allows the company to stabilize operations and zero in on the root cause of major inefficiencies to capitalize on the major areas for improvement.

This section explores the initiatives that secure the foundation and prepare the company for continued success in the implementation work. The first step of strengthening the foundation is to clear the field, which helps the team understand the existing state of operations. Next, the team will immediately address on time delivery.

5.1 Clear the Field

In farming, land preparation is described in 3 steps. First the field is plowed to overturn the soil. Next, it is harrowed to break up clumps. Finally, the field is leveled, setting up channels and roads to support proper irrigation. However, before any land preparation begins, the field must be cleared. If the field is not properly cleared, rocks will break the plough, or weeds will over run the crop. Clearing the field is a tedious task that provides nothing to show for all the hard work, but it is vital for a fruitful harvest.

The first initiative in Company X's strategy is to clear the field. Here, the aim is to identify and remove the roadblocks that stand in the way of progress. Just as it can be tempting for a farmer to plough through the rocks and weeds and begin planting their crop, it is tempting for Company X to look past current fundamental issues (*i.e*. the rocks) and prematurely towards improving their plant using state of the art technology.

Company X, like many job shops, has numerous "rocks" (*i.e.* hidden factories) that must first be discovered and eliminated. The journey begins by going to the Gemba, mapping the existing processes, and removing the roadblocks that stand in the way of improvement.

5.1.1 Understand Existing State

Tools: Process map, Gemba

Behaviors Fostered: Communication

The first step of understanding the existing state is to observe the overall process. To learn the process, several techniques can be used. The first, is going to the Gemba, or the place of work, to observe. Next, in collaboration with the employees from all functions, the process steps can be mapped out. Company X mapped out the steps from A to Z, from the customer requesting a quote to a product being delivered.

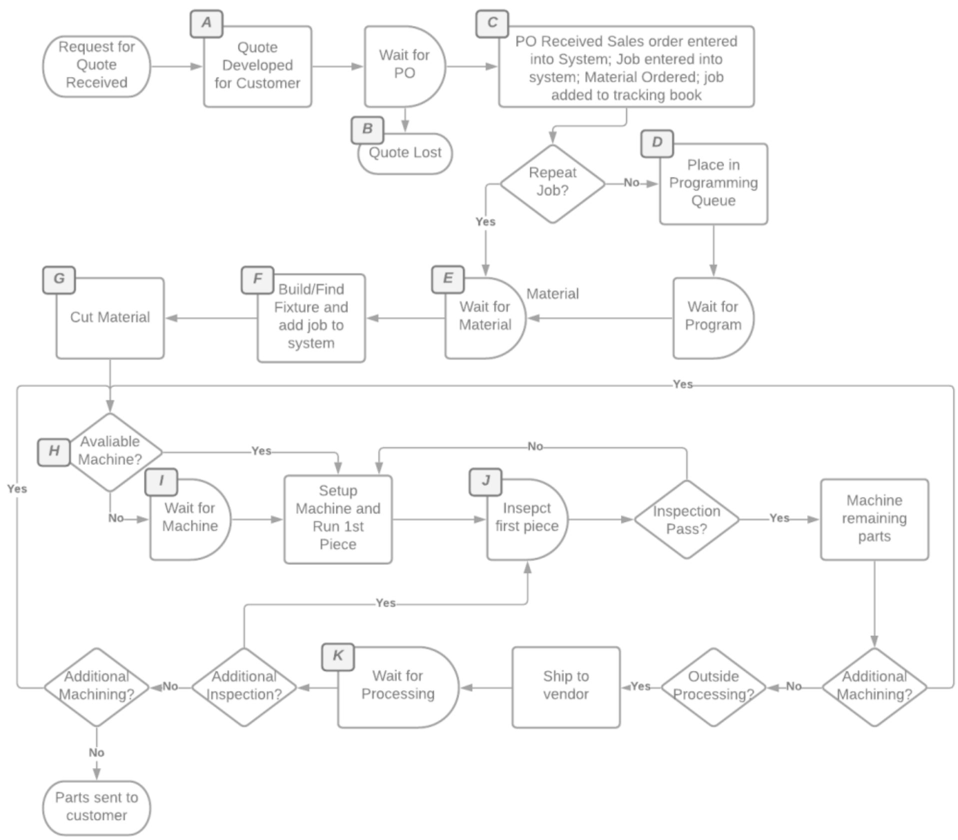

Figure 5: Process map example from Company X depicting the key step required from when a customer requests a quote to when parts are delivered

The process mapping exercise allows the team to identify several areas of non-value add waste. It also brings to light the frustrations that employees have with the existing process, and opens new avenues for communiction, as team members at all levels are interviewed which may be the first time some employees voices are heard. Some employees will be optimistic and eager to engage. Others will express trepidation, having concerns that it would be nearly impossible to accurately map out the complexity associated with the operations in most job shops.

The process map should start as a high level overview of operations to help the team identify the most pertinent issues and the roadblocks that stand in the way of future improvements. It should help the team understand how each individuals work impacts the rest of the team.

Developing the process map should be done as a team. Working together to make a visual aid that shows how things flow through the shop creates alignment among the employees. A common approach, and the one used at Company X, was to bring the key stakeholders into a room, and talk through each step of the process, documenting each one on a whiteboard. Once the process is agreed upon, a draft process map is created and shared with the various team members at the company again. The team can review the existing state, and begin to note the issues that exist. Looking at the process in the organization highlights iniefficiencies that the team faces and helps break down complex problems into smaller, more solvable challenges.

Once a draft process map is created, it should be provided to various team members at different levels of the company. These team members can make notes of the problems they identified during the exercise directly on the process map and regroup to categorize issues discovered in the existing process. It can be helpful to tie each process issue back to tue value it impactd most directly. Once the value is identified, the issues can be prioritized by the team.

For Company X, processes that impact safety and OTD were prioritized into strengthening foundation (SF). Without safety, teams are unable to perform their job. Without strong OTD performance, demand declines resulting in no work for the team to do. The processes that were secondary to OTD and Safety, have an impact on lead time and cost, and these processes will be addressed next as the team synchronizes operations (SO). Table 6 summarizes the categorization.

Table 6: Process Map issues and corresponding impact on value drivers categorized into phases of the operational excellence framework. For example, the issue represented by Note A has a primary impact on Lead Time and will be addressed as part of the Strengthen Foundation Phase.

Note	Description	Phase	OTD	Lead Time	Cost
A	*Quotes returned late; No follow up with customer; no way to plan for future work*	SO		●	
B	*No information on how many quotes were lost and why they were lost*	SO		●	●
C	*Sales orders have multiple promised dates; Machine demand not specified; job does not specify the promised dates*	SF	●		
D	*No priority; no visibility to due date; addressed on an ad hoc basis*	SO		●	●
E	*Material arrives late; team not notified of material arrival*	SF	●		
F	*Machine demand not specified; fixtures take multiple days to track down*	SF	●		
G	*Material moved from upper warehouse, to lower warehouse, back to upper warehouse*	SF	●		
H	*If job is hot, stop machine, remove old job, and setup for new job*	SF	●		
I	*Long setups, fixtures not ready, tools broken/missing.*	SO		●	●
J	*No priority; sit in inspection for a long time*	SO		●	●
K	*no queue; address on ad-hoc basis*	SO		●	●

The process mapping exercise highlights several challenges the company faces. Once the process steps that drive complexity for the company are identified, the team can begin to address the root cause.

5.1.2 Shop Floor 5S

Tools: Process map, 5S, Standard Work

Behaviors Fostered: Collaboration

The leading cause that contibutes to the issues identified during process mapping is often a disorganized workplace. This is why one of the foundational steps of lean is 5S. In a job shop, where the company has a variety of different parts, each of which has its own unique processes, individuals create and rely on work arounds. Rather than taking the time to develop robust standardized work, using a set of common tools, processes are adjusted on the fly to put out the most recent fire. True to human nature, teams and employees choose the path of least resistance. What is faster in the moment often leads to complexity and confusion in the future. Processes become difficult to follow, tools become hard to find, and the shop floor becomes a chaotic nightmare.

Job shops often relies on shared tools, machinery, and work areas. The problem is that no individual is held accountable for making sure these tools and work areas remain clean and organized. Just as a single dirty dish in the sink at home quickly turns into a pile of dishes that no family member wants to clean up of, a mess on the shop floor that starts small, continues to grow with no one claiming responsibility or taking the time to clean it up. The key is to avoid having any dirty dishes in the sink. When dirty dishes fill up the sink, family members get frustrated because they can't find the mug they need to drink their morning cup of coffee. In the same way, employees become frustrated because they cannot find the tools to do their job, or their co-worker left the tool they needed in a suboptimal condition, or broken. This leads to frustration from employees, hoarding of tools, and a shop floor that resembles a sink full of dirty dishes.   Company X is similar to many other job shops in that some areas of its workspace are disorganized and have unnecessary tools or items that take up space and distract from efficient work.

In addition to the challenges with shared workspaces, each unique part requires several machining operations, each of which require unique fixture for setups.   Early on in the setup process, it is possible for a shop to manage the fixtures without an inventory system. As the shop grows, the number of fixtures required increases. Company X did not have a robust inventory system for their fixtures. Fixtures were found all over the shop, with inconsistent labels. Furthermore, fixtures that had not been touched for over 10 years were still being stored. Company X was running out of space to store the fixtures. The production planning team was responsible for getting fixtures for the machinists, so that machists could focus on making the parts for the customer. While this helped the machinists focus, it took away from the time the production planning team needed to manage the flow of product on the shop floor. Instead of doing the job they needed to be doing, the supervisors were in the warehouse digging through boxes for days on end. This slowed down all of the orders thoughout the shop, as there were more than 25 operators for every one production manager.

The first step is to free up the manangement team so that they can support their employees. For company X, this meant developing a solution for fixtures, such that the production managers could find them in a matter of minutes, rather than a matter of days. The next step is to clean up shared shop floor spaces to remove what is waste, and organize what is needed. The final step is to address the individual workstations. These steps will be discussed in more detail below.

5.1.2.1 Fixture Inventory System

Company X had thousands of fixtures that were stored in a separate warehouse for use in repeat jobs. Keeping fixtures is a necessary waste. On aveage, a job at Company X requires 25 hours of fixture development. If all jobs required a new fixture, fixture development would account for 30% of total machine hours. Because Company X kept all fixtures, the total fixture development time only accounted for 2% of total machine hours versus 30% if if new fixtures were made for every job. Company X accumulated a large inventory of fixtures because the company never disposed of any fixtures even after jobs were completed and projects were finished. Additionally, their system for storing fixtures made the process of finding a fixture extremely time consuming. It was estimated that each fixture took 4 hours of dedicated time to find, however there were significant deviations from this average.   The people looking for the fixtures needed to have context on what they were looking for. At Company X, this was the production leads. There were only 2 production leads. The production leads would spend 10% of their working hours looking through boxes. Some weeks, however, they spent more than 50% of their time on this activity.

The production lead time is extrmely valuable because they manage the flow of product. Company X needed them to plan production, not spend hours digging through boxes to find a fixture. Figure 7 shows the warehouse where fixtures were stored. 6 ft x 6 ft x 8 ft Pallets were stacked with boxes. The boxes were then wrapped to keep items from falling. The pallet was then placed on a shelf. When a production lead went to look for a fixture, they had to pull each pallet down, remove the plastic wrap, and beging sorting through anywhere from 10-30 boxes. This process was time-consuming and unsafe.

Figure 6: Warehouse holding fixtures for Company X prior to implementation of inventory system

The problem was overhwleming for the team. The problem was too large to solve in one day as it would impact production. The team broke down the problem and proved out standard procedure for fixutre inventory using fixtures from just one pallet. Once the procedure was well defined and agreed upon, employees were trained to work through the remaining pallets during downtime.

Each fixture was assigned a location in inventory and stored in the ERP system. Any employee could look up the a fixture by product part number. Upon lookup, they would be given a location. The location would point the employee to a bin, where they would find the fixture. The fixture could then be checked out of inventory for use on the shop floor. Once the fixture was done being used, it would be checked back in to an inventory location for future use.

Figure 7: Warehouse holding fixtures for Company X following the implementation of the new fixture inventory system

Within a few weeks, over half of the fixtures had been placed in inventory. In just two months, the remaining fixtures in the warehouse were placed in inventory. The new system shortened the average time spent looking for fixtures from hours to minutes. More importantly, the employees had a standard work that any employee follow to find a fixture. The production leads were able to focus all of their time on supporting operators and improving on-time delivery performance.

5.1.2.2 Shop Floor Cleanup

Excess items and disorganization throughout the shop makes it exceptionally hard to find parts and tools when they are needed. Many job shops have a tendency to hoard materials in case they need them one day. While there will be instances where having a stockpile of items is beneficial, the benefits cnanot be reaped if you cannot find what you are looking for because it is impossible to keep organized.

Company X was no different from the majority of job shops. There were items that had not been touched in years scattered throughout the shop. The team needed to leverage 5S tools to sort, set in order, shine, standardize, and sustain, so this was what the implementation team set out to do.

5S can be difficult to implement in the job shop environment. Job shops require more tools than a production environment because the parts that the operators are working on are constantly changing. Many operators strongly oppose 5S, because they have worked in job shops that standardized the wrong things. The operators end up not having the tools they need, because the job shop was not prepared for the variation.

Because many operators are against 5S activities, it is best to reframe the process to drive engagement and excitement about cleaning and organization. Company X did this by first having the management team conduct a red tag event in which all items in shared spaces were marked to keep or to scrap. This showed the operators that they had support from upper management, and not all the burden would fall on them. During this initial activity, Company X made space to allow for all material pre-processing to be done in the upper warehouse, which is used more for storage and less for daily activities. Previously, material was transported from the upper warehouse to the lower warehouse, cut to length, and then transported back up to the warehouse for storage until the job was ready to start. This excess material handling was costly and hazardous. The team also removed nearly 3 dumpsters of items that were no longer in use. This opened space for the team to place another machine in their space constrained environment, and to set up a tool room to allow for tooling presets which will be discussed in Chapter 6. Common areas were taped off and designated for visual queueing to support a visual workplace.

The next step was to get the operators involved. Cleaning up the shared work areas is a good first step, but the collective team needs to be on board to sustain the improvements. The best way to introduce the 5S activity is to start with a few individuals that are frustrated about the state of the shop, and eager to make improvements.

To help with this step, small groups should be formed consisting of a few operators and the assembly team. The team should be given the tools they need to sort, set in order, shine, standardize, and sustain. Members of the management team should be present to support the operators as they work through their area. At Company X, the management gave operators a rule of thumb to follow, in which anything that had not been touched in 2 weeks should be removed from their work area or disposed.

The process was gratifying and provided several benefits. For example, in starting and exercising5S process, broken tools were found that were required for upcoming jobs. The lead time on the specialized tools was several weeks, which if not found would have resulted in a late order. These stories were shared throughout the shop until the rest of the team started to see the value in creating a clean and organized environment.

The improvements at Company X resulted in a safer, more efficient work environment. Employees started to take responsibility for their work areas. Tools were taken care of, reducing unexpected tooling costs, or contributing to late orders. Operators knew where to find what they were looking for. The number of times operators had to leave their workstations decreased because they were better prepared for upcoming jobs.

It is important to remember that the first pass is not sufficient. The team had to iterate and improve. The process should be revisited repeatedly to ensure the improvements are sustained. This also allows for any adjustments to be made to ensure the optimal shop floor organization is achieved.

5.1.3 Data Management System Cleanup

Tools: 5S, process mapping, Standard Work

Behaviors Fostered: Communication

Many job shops have started to adopt enterprise resource planning (ERP) systems to manage the supply chain, customer relationships, manufacturing, finance, and other business processes. Many ERP systems are designed for production environments. The few systems that are designed to support job shops typically will not align perfectly to the way the shop has chosen to operate. It is often cost prohibitive to build customization into the ERP system, and therefore workarounds are developed. Furthermore, many job shops fail to utilize the full potential of the ERP system due to lack of training. If standardized procedures are not designed, the data may not be properly managed, and it will be difficult to draw conclusions about past performance or make predictions about future performance.

Company X was using an ERP system to manage business activities. When transitioning from paper to the ERP system, they did not leverage the full benefits of the system. When the system did not work for their needs, they developed a work around. The workarounds made it extremely difficult for anyone to look at the data and understand what was happening on the shop floor.

The best technique to address this situation is to work with the key stakeholders to map the processes and data to the products flow. Company X discussed who these key stakeholders would be, and brought together production engineers, production management, and information technology employees to help optimize ERP use. This team built out process maps to understand where the system lacked correct or complete information. Next, the team conducted a 5S activity on the data. The team sorted the data, getting rid of incorrect items in the system. Next, they set the data in order, making sure the proper information was being used by the system properly. After that, they shined the data, addressing inconsistencies in how data was being stored. Next, they developed standardized processes for the new processes. Finally, a weekly stand up was used to sustain the improvements. Here, the team investigated training to extend existing functionality.

The ERP system cleaning made it possible for the team to have confidence in the data. Before cleaning up the ERP system, the team would often walk out to the shop floor to check that the ERP system was correct. After the changes, the team had built confidence in the data, and no longer needed to walk around searching for an item in the shop to get the status of work. This confidence was necessary for both on-time delivery performance improvements and workflow digitization which will be discussed in later sections.

5.2 Immediately Improve OTD

Once the roadblocks are removed, the team must address any areas that demand immediate attention. To drive value for their customers, a company must first provide a safe working environment, then provide quality products to their customers on time. Company X had addressed safety concerns, had exceptional quality performance, but had poor on time delivery performance. This section walks through the steps that Company X took to immediately address their poor on time delivery performance.

5.2.1 On Time Delivery Performance Issues

Tools: Process mapping, Gemba walks

Behaviors fostered: Communication

Process map exercises and Gemba walks help the team identify the root cause of gaps in performance. For Company X, it highlighted the processes that led to poor on time delivery performance.

Looking back to the process map developed from when an item was quoted to when it was shipped to the customer, Company X identified that steps C, E, F, H, and K, described again below, all contributed directly to poor on time delivery. The team dove into each one of these steps to better understand why it was causing a problem. Next, they looked at the actions that could be taken to address the problem, prioritizing based on impact to on time delivery performance.

Step C is when the PO is received. At this time, the sales order and job number are entered into the system. The sales order had delivery dates and promised quantities, but the job only contained the total quantity that would be produced. There was nothing linking the sales order to the job, making it extremely difficult to determine when parts on the floor needed to be completed for the customer.

Step E is when the team is waiting for material. When an order is placed, material is ordered for the job. There was no standardized process for notifying the team that an order for material was placed, or for notifying the team of when the material would be arriving. On certain occasions, the lead time on some materials would be so long that it would cut into the total time required to machine the part for the customer, thus ensuring a late delivery even before the job was started.

Step F is when the team builds or finds the fixture and the routing for the job is added to the system. At this point, the machining steps are known, however, it is not until the job is ready to go out on the shop floor that the routing is completed and stored. The team does not have any information on how much time the job will take or what resources it requires until step F. It is difficult to predict machine load without a complete routing for all the jobs in the system. Furthermore, the team does not know when a job needs to start because they have no visibility to how long each process will take.

Step H is when the team checks for machine availability. Rather than planning to load the machines, the team will process what they believe is the most important product to process that day. This may be a part that a customer called about, or one that was forgotten about and is now almost due. If there is a hot job, a machine will be freed up so that the more urgent work can be completed. This results in more changeovers which leads to longer setups, higher work in progress. It decreases efficiency and quality, resulting in longer lead times and poor on time delivery.

Step K is where the team waits for processing. Most job shops work with external vendors for outside processing on most products. The parts must be shipped to the vendors for processing. The lead time on processing varies. The team does not always know when to expect the parts back. There are also delays that are outside of the control of the team. This makes it difficult to schedule work on the machines in the shop because it is hard to predict when the parts will be ready.

5.2.2 On-Time Delivery Remediation

Tools: Visual Controls, Standard Work, Backwards Scheduling

Behaviors Fostered: Collaboration

In order to deliver on time, a job must start on time. The first step to starting on time was determining when the job needs to start. The production planning and management team developed a new process to enter jobs into the system so that each job was assigned a quantity, a due date, and routing steps. The change to this process allowed the team to look up any job and calculate when it needed to be started. Below is an example of the information the team had following the process change.

Table 7: Example of job information added to Company X ERP system to allow for backwards scheduling

Job	A
Due Date	12/22/2020
Quantity	57.0

Operation	Op Duration (Hours/Part)	Op Duration Run/Setup (Hours)	Non-Constrained Process Duration (Days)	Machine Load (Hours)	Total Duration (Days)
SAW			1		1
LATHE MED	0.1	4	0	10	2
HEAT TREAT			6		7
INSPECT			1		1
LATHE MED	0.1	25	0	31	4
MILL 4 MED	0.1	10	0	16	2
LATHE LG	0.15	20	0	29	4
MILL 4 MED	0.15	25	0	34	5
GRIND	0.15	23	0	32	4
CLEANING			1		1
INSPECT			0		0
MILL 4 MED	0.25	20	0	34	5
CLEANING			1		1
INSPECT			1		1
SHIPPING			1		1
Total	1	127	12	184	39

Table 7 shows an example of a job, with the quantity requested, the due date, and routing. The routing shows that the job will take a total of 39 days. A factor of safety is proposed to provide a buffer on production estimates. For this example, a 2.1x multiple is proposed to capture a 1.5x safety factor on the estimated process duration and a 1.4x multiplier to account for weekend downtime. The total time allotted to complete the job is 82 days. If the job is due Dec 22nd, the job must start 12 weeks, or 82 days before December 22nd. This puts the start date at October 1st.

This change addressed step C, linking the sales order and job together through a promised date. It also provided the team with the date they must have the material ready to begin the job.

The second step to starting a job on time is making sure that the team has the necessary materials and machinery ready and available to complete the job. The materials team now had visibility to the necessary start date. This served as a due date for the material to arrive for the job. The team could plan to have material on site so that the waiting time was eliminated at Step E. Additionally, when jobs were being quoted that had material that was difficult to procure, the team could collaborate with the customer to pre-order material so that Company X could hit the quoted lead times.

Once the job is started on time, the team must ensure it continues to progress through the shop. In the case that the start date had already passed, the job will get labeled as ‘HOT’. Labeling the job as ‘HOT’ reminds the team that it is a priority. It serves as a visual control that keeps the job from sitting on the shop floor, untouched and forgotten about. Additionally, each machine is tagged with a sheet of paper that has the name of the job that is currently running, and the time required to finish the job, to the nearest half day. These signs provide the production management team with the approximate date the machine will be free. This helps the team plan production for the next couple days, reducing changeovers. By having a plan for what was running, the team could prepare the fixtures that were required to run the jobs. The visual indicators helped to address process steps F and H.

The team increased communication with outside vendors, preparing them for work that was headed their way. They also received updates on parts that were undergoing processing, which made it possible for Company X to plan for product that is being shipped back. This helped the team is better manage re-entrant flow, and reduce wasted time spent waiting for processing in step K.

In addition to all the process changes, the team met on a weekly basis to make sure they were working through the delinquent backlog and improving their on-time delivery performance for ongoing jobs. During these meetings, the team discussed what process changes were working best, and where they were having challenges. They collaborated on ways to improve the process further, and returned each week with updates on how the changes were working. As the team got delivery back on track, they were ready to focus on synchronizing operations to keep delivery on track, improve internal quality, shorten lead times, and start to drive down cost.

Chapter 6

6 Synchronize Operations

Once the foundation is secured and operations throughout the shop are stabilized, the information flow and material flow should be aligned. This starts with capacity planning and scheduling to maintain on-time delivery performance. It is followed up with setup time reductions, and efficiency improvements to enable flow.

6.1 Capacity Planning and Scheduling

Little's Law is used to understand how product flows through the shop. Little's Law shows that lead time (W) through the system is directly proportional to the WIP, or the number of items in the system (L). For product flowing through a factory, the lead time is broken down into processing time and waiting time.

$$WIP = (Processing\ Time + Waiting\ Time)\ (Throughput) \qquad \textbf{(Eq. 6)}$$

When there are no capacity constraints in place, the throughput approaches infinity, and the lead time approaches zero. In a job shop with constrained capacity, the throughput is limited. Waste in the system increases the processing and wait times which increases the total lead time. Once way to improve lead time is through removal of waste in the system. This is done through setup time reduction, 5S, and other lean tools used throughout this research. In addition to the removal of waste, the total number of parts in a system, or the WIP, also impacts the lead time. For a given throughput, the more parts in the system, the longer time on average each part will take to be processed through the system. Therefore, it is important to level load the system, feeding the system the minimal WIP required. This will minimize the average lead time for a given throughput.

To level load the system, it is helpful to visualize the system. This is done by building a chart that shows the total amount of work in the system over time. The process for creating this chart is described using a simple scenario, where a shop has three jobs. Each job has unique routing, quantity, and due date. Once the load is visualized, the team can balance it. Using backwards scheduling to ensure jobs are started on time, the team can maintain the minimum WIP required to move product through the system. This reduces waiting time, and ultimately the total lead time. After working through the simple scenario for balancing the work on 3 jobs, the process for applying the same analysis for a job shop containing hundreds of jobs will be described.

The best approach is to start simple and add complexity. The first view of the system will consider total machining load independent of machine type. The team can start by level loading the total machine hours throughout the shop, and then increase granularity by level loading specific machines.

6.1.1 Understand Existing Load

Tools: Visual Controls, Backwards Scheduling

Behaviors Fostered: Curiosity

To understand load, a load chart to visual machine hours required over time is used. To determine the machine hours over time, the team aggregates demand for each machine from the routers for the jobs in the system. The job router provides information about the steps the part must go through before it is completed. There are two types of operations. The first are machining operations, in which the job shop has limited capacity. The second are the non-machine operations, where capacity can be increased if necessary. The loads from the machining operations are measured in hours. The duration of the machine steps, and the non-machine steps in days, and provide the timeline of when the machining operations will take place. With this information, the start date for the job, and each operation can be determined using backwards scheduling.

There are three scenarios to consider. First, the job is on-time. This means the job start date is the same as the date in which the job was started. Furthermore, all subsequent operations are started by the specified start date. Second, the job is late. This means either the job started late, and all operations were late, or the job started on time, but fell behind schedule. Third, the job is early. This means the job was started before the required start date, leaving the team extra time to complete the job.

This example will use a factor of safety to provide a buffer on production estimates similar to the example outlined in Table 7. The 2.1x multiple is proposed to capture a 1.5x safety factor on the estimated process duration and a 1.4x multiplier to account for weekend downtime.

Additionally, for the following example it is assumed that "today" is 10/1/2020.

The backwards scheduling process can be applied to Job A. Using Job A's due date of 12/22/2020, 10/1/2020, or "today" is the required start date.

Table 8: Job A Routing Example

Operation	Machine Load (Hours)	Total Process Duration (Days)	Duration with Factor of Safety (Days)	Calculated Operation Date	Revised Operation Date	Week
SAW		1	2.1	10/1/2020	10/1/2020	0
LATHE MED	10	2	4.2	10/3/2020	10/3/2020	0
HEAT TREAT		7	14.7	10/7/2020	10/7/2020	0
INSPECT		1	2.1	10/22/2020	10/22/2020	3
LATHE MED	31	4	8.4	10/24/2020	10/24/2020	3
MILL 4 MED	16	2	4.2	11/1/2020	11/1/2020	4
LATHE LG	29	4	8.4	11/5/2020	11/5/2020	5
MILL 4 MED	34	5	10.5	11/14/2020	11/14/2020	6
GRIND	32	4	8.4	11/24/2020	11/24/2020	7
CLEANING		1	2.1	12/3/2020	12/3/2020	9
INSPECT		0	0	12/5/2020	12/5/2020	9
MILL 4 MED	34	5	10.5	12/5/2020	12/5/2020	9
CLEANING		1	2.1	12/15/2020	12/15/2020	10
INSPECT		1	2.1	12/17/2020	12/17/2020	11
SHIPPING		1	2.1	12/19/2020	12/19/2020	11
Total	184	39	81.9	12/22/2020	12/22/2020	

From this data, the machine hours are plotted by week to develop a load chart. The chart shows that Job A will require machine capacity in weeks 0, 3, 4, 5, 6, 7, and 9.

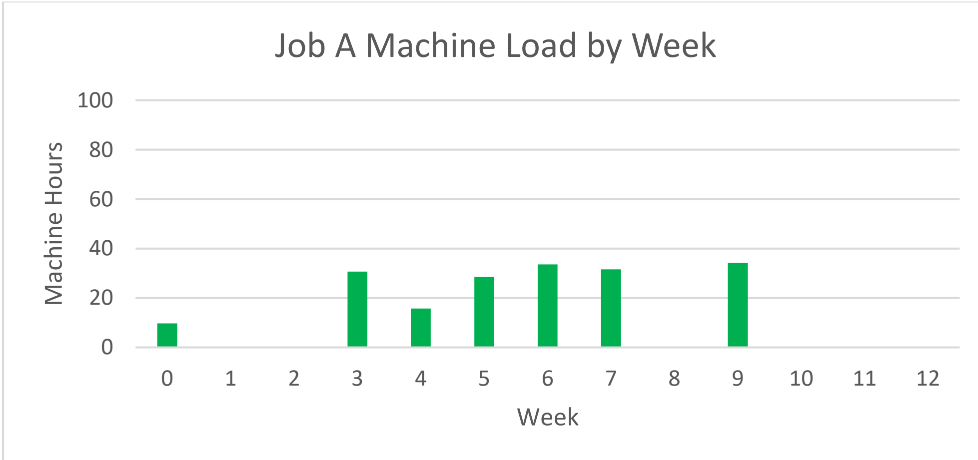

Figure 8: Job A Machine Load Chart depicting the required machine hours by week

The second scenario is shown with Job B. Job B is due on 12/12/2020. This means the start date for the job is 8/20/2020. The required start date passed; therefore the job is late. The operation start date must be revised to "today" or 10/1/2020.

Table 9: Job B Routing Example

Operation	Machine Load (Hours)	Total Process Duration (Days)	Duration with Factor of Safety (Days)	Calculated Operation Date	Revised Operation Date	Week
SAW		1	2.1	9/4/2020	10/1/2020	0
MULTUS	36	5	10.5	9/6/2020	10/3/2020	0
HEAT TREAT		7	14.7	9/16/2020	10/13/2020	1
INSPECT		1	2.1	10/1/2020	10/28/2020	3
MULTUS	26	4	8.4	10/3/2020	10/30/2020	4
LATHE XL	23	3	6.3	10/12/2020	11/7/2020	5
MILL 5	36	5	10.5	10/18/2020	11/14/2020	6
DEBURR		1	2.1	10/28/2020	11/24/2020	7
LATHE XL	49	7	14.7	10/31/2020	11/26/2020	8
MILL 5	28	4	8.4	11/14/2020	12/11/2020	10
EXTERNAL		7	14.7	11/23/2020	12/19/2020	11
INSPECT		1	2.1	12/7/2020	1/3/2021	13
SHIPPING		1	2.1	12/9/2020	1/5/2021	13
Total	196.4	47	98.7	12/12/2020	1/7/2021	

Job C highlights the final scenario. Job C is due 12/30/2020. In this case, the first 4 operations have already been completed. The next operation start date is 10/11/2020. The operation is ready to start "today" on 10/1/2020. The operation date is revised to 10/1/2020 and the following operations are scheduled off "today's" date.

Table 10: Job C Routing Example

Operation	Constrained Load (Hours)	Total Process Duration (Days)	Duration with Factor of Safety (Days)	Calculated Operation Date	Revised Operation Date	Week
SAW		1	2.1	9/22/2020	Completed	
LATHE MED	11	2	4.2	9/24/2020	Completed	
HEAT TREAT		7	14.7	9/28/2020	Completed	
INSPECT		1	2.1	10/13/2020	Completed	
LATHE MED	45	6	12.6	10/15/2020	10/1/2020	0
LATHE LG	41	6	12.6	10/28/2020	10/13/2020	1
MILL 5	26	4	8.4	11/9/2020	10/26/2020	3
CLEANING		1	2.1	11/18/2020	11/3/2020	4
INSPECT		1	2.1	11/20/2020	11/5/2020	5
EXTERNAL		7	14.7	11/22/2020	11/7/2020	5
MILL 5	31	4	8.4	12/6/2020	11/22/2020	7
MILL 4 MED	36	5	10.5	12/15/2020	11/30/2020	8
INSPECT		1	2.1	12/25/2020	12/11/2020	10
SHIPPING		1	2.1	12/27/2020	12/13/2020	10
Total		47	98.7	12/30/2020	12/15/2020	

The load chart for each job individually does not provide much value. The next step is to model all the jobs in the shop on a single load chart. Figure 10 shows the load chart for jobs A, B, and C. There is significant variation in the machine hours required from week to week. If a throughput of 60 hours/week is assumed, not all the machining can be done in weeks 0, 3, 4, 7, or 8. To visualize priority for each job, colors are used and discern what work is early, on time, and late. Here, the early work is designated in orange, late work in red, and on time work in green. The next step is to look at how to balance the load through the shop.

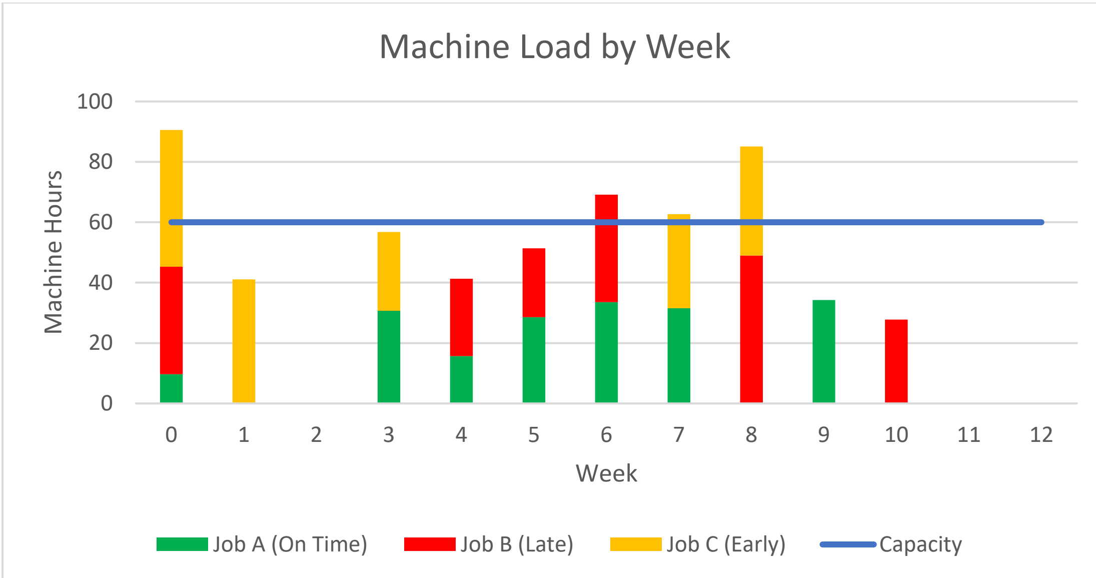

Figure 9: Unbalanced Load Chart for Jobs A, B, and C showing the total machine hours by job each week

6.1.2 Balance Load

Tools: Visual Controls, Backwards Scheduling

Behaviors Fostered: Customer Focus, Accountability

The goal is to achieve a balanced load where the work is on time, and the total load is just below the capacity each week. In the example, only Job A is on time; Job B is late, and Job C is early. The shop needs to ensure product is delivered on time; therefore, Job A and B should be prioritized, and Job C should be shifted out.

The load chart below shows what happens when Job C is shifted out. Job C moves from early to on-time status, and Job A remains on-time. If Job C were prioritized, Job A would shift from "on-time" to "late", resulting in 2 late jobs, and one early job.

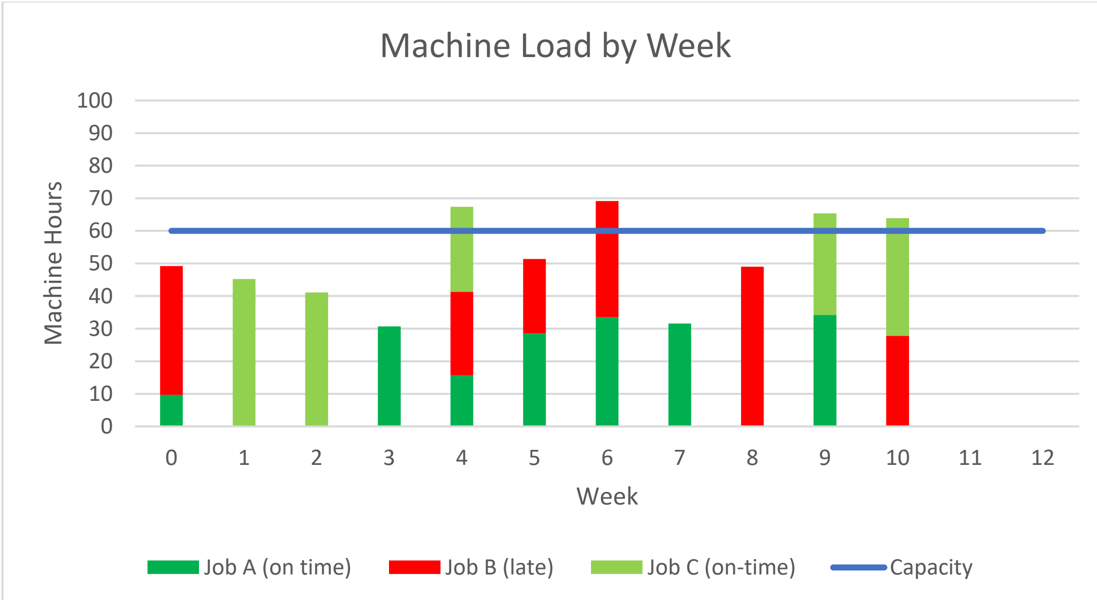

Figure 10: Proposed Balanced Load Chart for Jobs A, B, and C in which Job C is shifted from early to on time such that there is a more even distribution of work across the all weeks

To stay within capacity constraints, the excess load in Week 4 can be processed at the beginning of Week 5. The same is true for the excess in week 4, 6, 9 and 10 by doing processing early week 5, 7, 10, and 11 respectively.

6.1.3 From Example to Practice

Tools: Visual Controls, Backwards Scheduling

Behaviors Fostered: Customer Focus, Accountability, Curiosity

The load chart can be extended to model all the jobs in the plant. Rather than discerning between specific jobs, a simplified view is used where the machine hours for the “early”, “on-time”, and “late” jobs are plotted for all the jobs in the shop. Company X, had a load profile like that in the figure below. most work was either late, or extremely early, either way missing optimal performance. Additionally, there is significant variation in load from week to week.

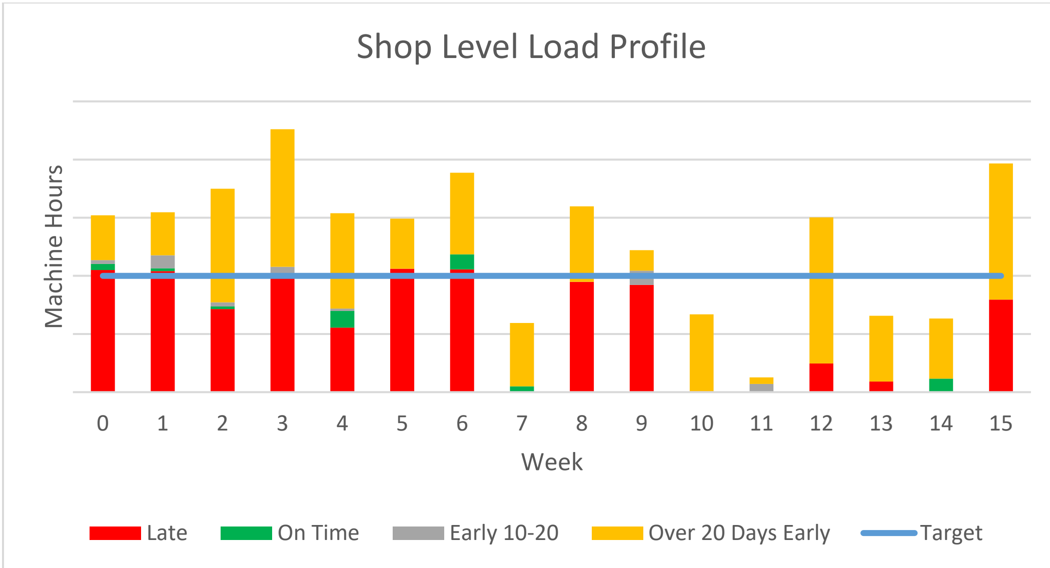

Figure 11: Unbalanced Shop Level Load Profile representing the aggregated machine demand for all jobs in the shop by week. Most jobs are either late or over 20 days early.

Once the team had visualized the load, they could balance it. Using at the chart, the team at Company X identified that they could shift out the early work, and focus on the late work. Focusing on the late work and waiting to release early jobs reduced the amount of WIP in the system, therefore reducing the total lead time. The team was able to put focused pressure on the late jobs without being distracted by early work.

To avoid early work becoming late, the team developed a start date metric. Using the start date calculation described above, each job and operation was given a start date. A report of the jobs that needed to be started was provided to the team. This kept the team from overlooking jobs and missing the required start date.

Over time, the team will be able to balance the load with the capacity in the shop to achieve the desired load profile below. The shop will be able to process work more quickly, improve on time delivery performance, reduce WIP and drive predictability.

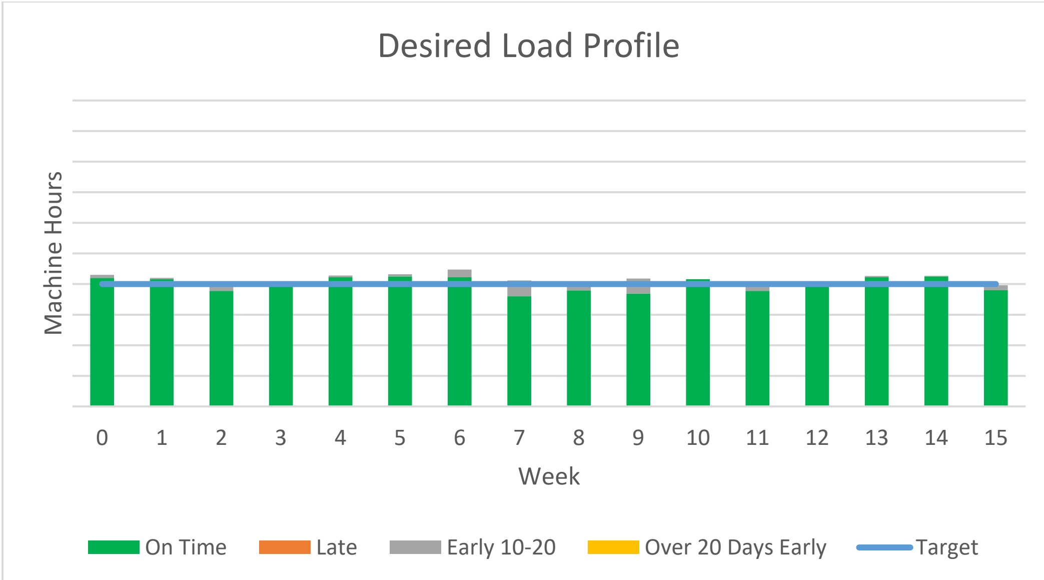

Figure 12: Balanced Shop Level Load Profile in which the machine hours are near or below the theoretical capacity of the shop and all of the work is on time or 10-20 days early.

Because Little's Law works for single workstreams, the team can extend this process to individual machine groups to balance load at a more granular level.

6.1.4 Maintain Balance

Tools: Visual Controls, Backwards Scheduling

Behaviors Fostered: Accountability, Customer Focus

To maintain balance throughout the shop, the team should review the load charts frequently, and align their throughput with the size of their backlog by adjusting staffing levels. Incorporating best practices from Sales and Operations planning, the team should conduct perioidic review of the backlog and adjust the machine hour capacity accordingly. If the companys sales increase, the backlog will grow. If the the machine hours remain constant, the team will not be able to process the work. Over time, the load will become unbalanced, because work will be late. If the company's sales decrease, the backlog will shrink. The team will begin to reach into their backlog to fill up avaliable capacity. Over time, the backlog will run dry leaving no future work to fill existing capacity.

To determine the optimal capacity, the team should correlate the machine hours with sales. This will provide the team with a throughput rate in machine hours per dollar. Looking at the average machine hours worked per week, the team can determine when the backlog will be depleted. Monitoring backlog levels will help the team maintain a balanced load. The sales team will need to work with the operations team to determine when to get more competitive on pricing to fill excess capacity, and when to increase pricing to maintain managable growth.

The process does not solve the day-to-day scheduling of jobs in the shop, but it ensures that the right jobs are in WIP, which simplifies the decisions that the production manangement team must make to schedule the shop. The production team will leverage backwards scheduling to ensure that jobs and the individual operations start on time. As the job shop shifts to a digitized workflow they can leverage the digital twin to support with more detialed scheduling. This is discussed in more detial in Chapter 7.

6.2 Enable Flow

In the previous section it was shown that balancing the load in the shop is one way to decrease lead times, however it does not address the waste in the shop that contributes to longer processing times. This section discusses how a job shop can reduce lead time and increase throughput by addressing waste. The following sections outline the initiatives that will reduce waste to enable flow, and support the value-generating principles: quality, on time delivery, lead time, and cost.

6.2.1 Create Centralized Tooling Repository

Tools: Setup Time Reduction, 5S, Standardized Work

Behaviors Fostered: Accountability, Collaboration

One of the major challenges for a job shop is the setup time, or the time required to switch from producing one component to another on a machine. At Company X, 10% of the total Machine hour were spent on setups. Setups include finding tools, fixtures, and setup sheets for the next job, exchanging the old fixtures and tools for the new ones, mounting the new tools, and then conducting positioning and calibration of the tools to complete the first component. All this time is wasted time, because both the machine and machinist are tied up on work that does not contribute directly to the product for the customer.

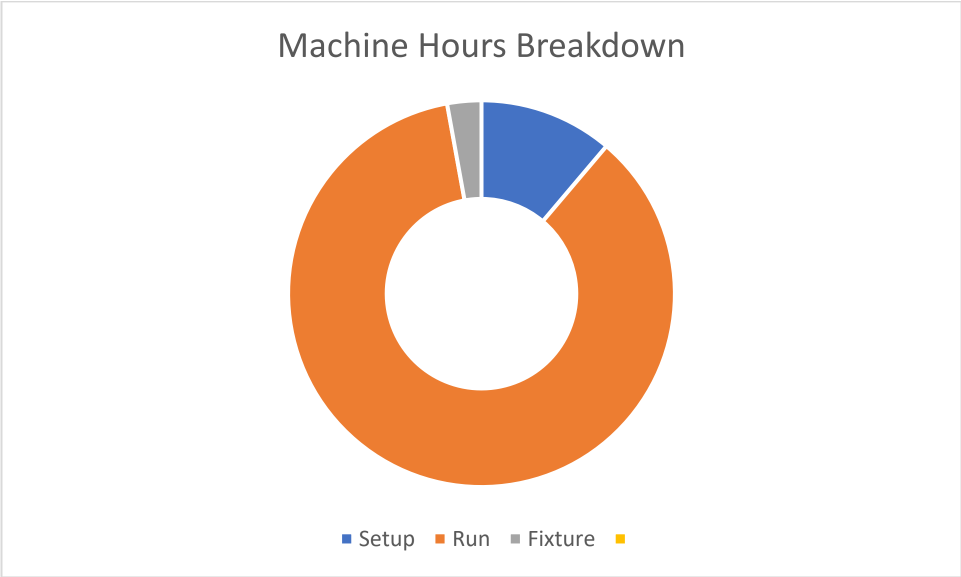

Figure 13: Company X Machine hours breakdown between setup, run, and fixture time[1]

The CNC Machines used in job shops require information about the tools being used to properly cut the part. There are many ways that the tool measurements can be made. Contact tool setting is a common process used by many job shops. In this process, the cutting tool is placed in a holder and a tool setter is moved to contact the cutting tool. The measurements are recorded by the machinist and then entered in the machine tool control. This process is time-consuming for machinists. The machinist must dedicate his or her time searching for the tools, making sure the tools are in good condition, and then manually setting each tool and loading the tooling data into the control.

The greatest opportunity to reduce the setup time is to move the responsibility for finding and setting tools from the machinist to a tooling team. The tooling team is made responsible for managing the shop's tool inventory, ensuring that broken tools get fixed or replaced, and

[1] Machine Hour data is from the actual machine hours logged at Company X in 2019

presetting all the tools required for upcoming jobs in the shop. Technology has improved such that tool setters can store measurements from the tool on radio-frequency chips that are embedded in the tool holders. The tooling team receives an operation sheet outlining the tooling required for the job. The tooling team prepares the tooling, running through all the necessary measurements. Next, the team places the tools on a cart, and the cart is then brought to the machinist, who can load the machine and begin cutting the first part.

The tooling team should create a centralized tooling repository. This process drives a more disciplined process for measuring and managing tools. That team can develop a standard process to setting up tools for machinists because it is a task that is repeatable. This will increase efficiency for the tooling team, leaving additional time for the team to manage and maintain the tooling inventory. Tools that were once stored all over the shop are organized in a central location. Machinists always know where to go or who to ask when they encounter problems with tooling. This in turn encourages accountability and collaboration among the team.

6.2.2 Machine Monitoring

Tools: Workflow Digitization

Behaviors Fostered: Accountability

Many job shops do not accurately capture data from the people and machines on the shop floor. For example, production data at Company X is entered manually into the system. In the field at this point, technology has advanced to allow for data to be captured from machines in real-time. The machines can count parts, record cycle times, and capture program data. Capturing data directly from the machine reduces the burden on the operators and improves the accuracy of the data. Accurate, real time data supports better decision making. The team can develop better scheduling tools, plan for preventative maintenance, address the leading causes of downtime, and quickly escalate critical issues to top management.

While machine monitoring has several upsides, it has the danger of being used or implemented incorrectly. The purpose of machine monitoring is to provide operators with the support they need, in turn making their jobs easier. It should increase autonomy, not take it away. The key to successful implementation of machine monitoring software is to work with the operators directly to test the different platforms and see what works well with the existing workflow.

At Company X, machine monitoring was introduced as a tool that could be used to help management identify the challenges that operators were facing. The team reviewed several different machine monitoring platforms, and ultimately chose to pilot one on several of their machines. The platform has enabled Company X to collect and document job specific data that will serve as part of the foundation for digitization.

6.2.3 Increase Machine to Man Ratio

Tools: Demand Planning, Cross Training

Behaviors Fostered: Drive

Job shops must look for opportunities to increase unattended machining. Unattended machining shortens lead times by allowing for increased machine utilization. Historically, machinists needed to be present at the machine to set up and swap parts. With new processes it is possible to load machines to run without direct supervision from the machinist. This allows the machinist to work on another machine while the original machine is still running. It also enables the shop to run machines overnight or on weekends, utilizing hours where machines were previously offline.

Creating fixtures is one way to run machines unattended and increase machine utilization. For jobs that are higher volume work, or involve a long-term contract with the customer, the team can invest in fixtures that allow the machinist to load multiple parts into the machine at once. This can be done using low tech solutions such as multiple vises, or higher tech solutions such as tombstones, which are multi-sided fixtures that rotate. Parts can be mounted to both sides of the tombstone, increasing the number of parts that can be milled without operator intervention.

Additionally, the team can look for opportunities to create work cells for products with similar machining requirements. Company X identified a set of parts that had the same routing. An operator that was running two machines concurrently had a third machine moved to their work area. Their efficiency average jumped from 92% to over 150%.

6.2.4 Increase Visibility

Tools: 5S, Standardized Work, Visual Controls

Behaviors Fostered: Accountability, Collaboration

It is hard to go out on the shop floor and immediately get a pulse on the existing state of operations at many job shops. The team should strive to make the current status of production visible so that everyone from operators to management can see how they are doing, and know what needs to be done.

To increase visibility, the job shop can extend the initial 5S work they had done to strengthen foundation and designate specific locations for the staging of product. Each machine group will have a staging area. When the staging area is full, it is visually clear to the team that there is a bottleneck at that machine group. The management team knows where to deploy resources. When the product is staged, indicators can be used to designate high priority work. This helps the machinists know what to start working on without consulting the production managers.

The visual queueing is a way of aligning product flow with information that the ERP system contains. Dashboards serve as another visual indicator, making it possible for employees to quickly look at a dial or a number and know if they are winning.

Chapter 7

7 Build the Factory of the Future

Once operations are synchronized and the foundation is secured, the team should leverage technology to build the factory of the future. Technology, when applied correctly, can help a company excel beyond the competition across all value drivers.

7.1 Digitize Workflow

One of the first steps for a company is to begin shifting to digitized workflow. Historically manufacturing has been governed by analog processes that lack visibility and scalability. The transition from paper processes to digital processes will support the company in making more informed decisions that enable growth.

7.1.1 Digital Production

Tools: Digitization

Behaviors Fostered: Drive, Accountability, Collaboration

Many job shops still rely on physical papers to document production processes. This is a slow, tedious, error-prone way of tracking product throughout the shop. There is valuable data that does not get captured and utilized, making it nearly impossible to improve without first transitioning to a digital medium.

The job shop should start by transitioning to digital routers. The digital routers will track and document workflow throughout the shop. By moving to digital routers, information about the manufacturing process such as best practices can be saved for the next time the part is produced. With high mix, low-volume type work, it is difficult to document, store, and access information about each individual part on paper. Digitization allows several attributes of a job to be recorded and reviewed by all stakeholders, at any time, in any place. This can speed up response time and improve decision making processes.

Once routers are digitized, the team can begin to develop in process inspection checks. This reduces the load on the inspection department, and helps the team catch quality issues early in the process. The measurement data can be documented and recorded as the parts are being processed. Management could access historical data to better support root cause investigation into quality issues. Customers could be given real-time updates on the progress of their parts, without having to call for updates.

The transition to the digital workflow will make it possible for the team to improve visibility to production. This will enable adaptability and responsiveness that shortens product lead times, improves quality, and reduces cost, providing value for the customers.

7.1.2 Digital Twin Simulation

Tools: Digital Twin, Demand Planning

Behaviors Fostered: Drive, Customer Focus

To support production scheduling and increase visibility to material flow on the shop floor, a simplified virtual model of the plant can be developed to simulate production. The simulation should be built modularly to allow for easier maintenance, configuration, and future improvements. Company X developed a simulation in which subcomponents of the model were built for specific tasks associated with production. The model includes tracking of work in process, monitoring the status of machines, sending orders out for external processing, setting priority for the work ready to be run, and diagnostics to understand performance under different operating scenarios.

The diagram below shows the digital twin model.

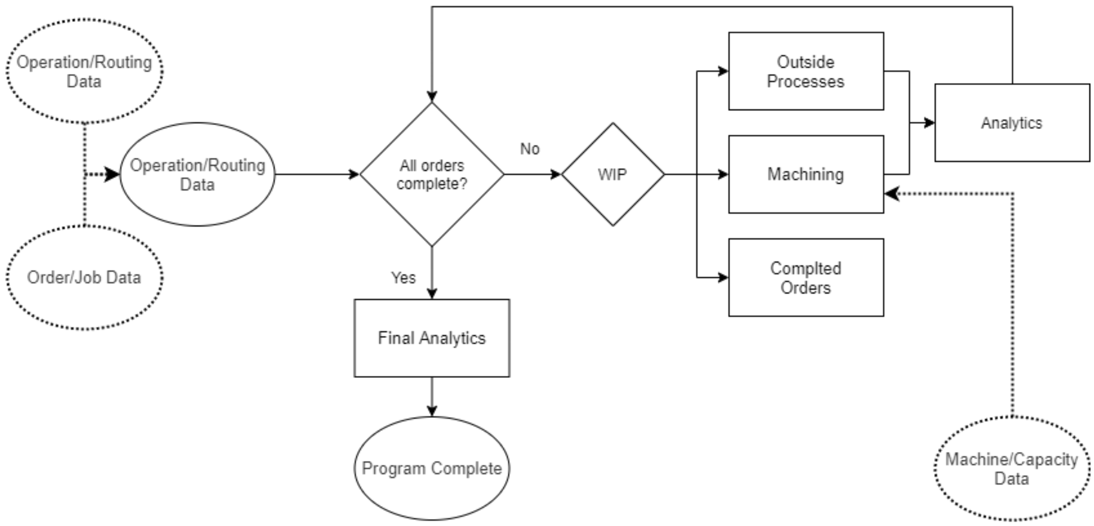

Figure 14: High level Process Flow Diagram for Digital Twin Model

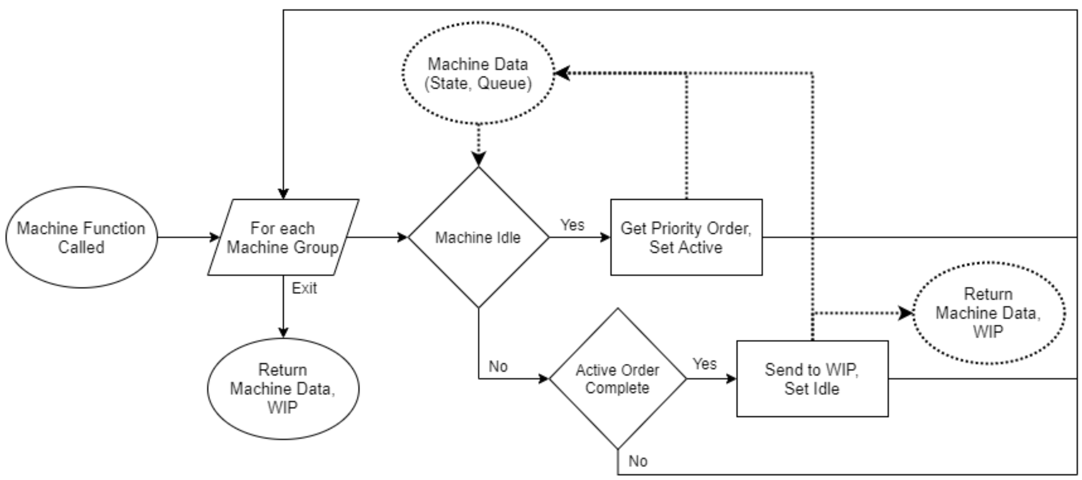

Figure 15: Machine level Process Flow Diagram for Digital Twin Model

Operation data and order data is inputted to the factory model, where the factory checks to see if there is work remaining to be done. When there is still work to be done, the WIP tracker, or the task master for the virtual factory directs the remaining work to the next machine group, or to outside processing. If an order had completed all required actions, the order would be moved into a completed dictionary and set aside.

The machine groups were used to represent the capacity in the factory. The virtual factory had 19 different machine groups, each containing several unique machines. An example of a machine group would be small lathes. When an order entered a specific machine group, it would join a queue. Once in the queue, a prioritization function was used to determine what order was worked on next. This prioritization function was where the company could compare different scheduling policies. In the case that a machine is currently working on an order, it checks the required machining duration to the current time spent in the machine, and if the required time is less than the current time spent, the process is completed and the order is sent back to the WIP tracker. When the machine is not being utilized, it will pull the next order from the prioritization function into the machine to complete its next operation. For the jobs that contained outside processing, a function was built to act in a similar manner to the machine groups. The function checked the time spent against required duration but assumed that all external processes could run in parallel, so there was no queue or prioritization. Whenever an order completed a specific process, either at a machine or an outside process, it would enter back into the WIP function.

A diagnostic function captured performance indicators from the virtual factory. It recorded machine utilization and order progression at each time step and then provided the output files required for the visualization of data.

The digital twin model is a useful and informative tool to support long-term investment decisions. Since the virtual factory was developed modularly, it can be built out further to leverage optimization techniques that support improved planning and scheduling. This will help the team identify the best way to plan production to maintain on time delivery, shorten lead times, and drive down costs.

7.2 Adopt and Compete with Additive Manufacturing

Tools: Setup Time Reduction, Additive Manufacturing

Behaviors Fostered: Drive, Accountability, Collaboration

Additive manufacturing has several advantages to the traditional subtractive manufacturing. Specialized tooling, programming, and setups are not required. This reduces production ramp up time and cost. Design changes are not cost prohibitive. Additionally, more complex geometries can be achieved. Additive manufacturing eliminates the need for part or project specific investments, which supports low volume production. While there are several advantages to additive manufacturing, there are also challenges that have limited the adoption of the technology.

Two of the major challenges with additive manufacturing are that the process is not fully understood, and that it is difficult to control. Currently, there are no industry specifications and standards for processing aerospace components. Additionally, there is machine-to-machine variability that results in inconsistent mechanical and material properties. Aerospace and defense components are often critical structural parts that must withstand extreme mechanical loading. The industry must have full confidence in the parts that are produced by additive manufacturing.

Because of the challenges with additive manufacturing, there is still a significant demand for traditional manufacturing. Rather than shifting production to additive manufacturing, the additive technology can be used in the production processes to decrease lead time and cost of traditional manufacturing. There is a major opportunity to do this by using additive manufacturing to build fixtures.

At Company X, fixture development accounts for 3% of machining hours. Fixture development uses up valuable manpower and machining capacity. For every fixture that is made, a program must be developed specific to that fixture. That machine will need to be set up with the proper tools and program to make the fixture. Then the machinist must machine the fixture, often on a machine used for production. This process consumes several valuable resources.

Company X and other job shops use additive manufacturing to produce fixtures. This gives the company with an introduction to additive. It also reduces the non-value add waste associated with fixture production.

Company X, and other traditional manufacturing job shops must monitor the shift towards additive. The transition to additive will only occur if additive succeeds to provides more value in terms of cost, lead time, and quality. While questions around the viability of additive still exist throughout the industry, the traditional manufacturing companies must work to become more competitive on lead time and cost. As the technology becomes more widely adopted throughout the industry, the company should explore new ways compete and adapt.

7.3 Automate Production

Tools: Automation

Behaviors Fostered: Drive, Customer Focus

Automation, when introduced properly, can drastically reduce costs and shorten lead times. Automation is most easily and effectively applied to low judgement and low dexterity work. The greatest returns come from automating mundane tasks that consume valuable human capital. Human capital should be reserved for tasks that require high levels of judgement and dexterity, and deployed to transition high-judgement, low-dexterity or low-judgement, high-dexterity work into low-judgement, low-dexterity work, so that it can be automated. The following section explores applications for automation in the job shop environment. The first step is to understand where employees spend their time. Next, the Lean tools, such as process mapping and going to the Gemba, are used to identify the work that is ripe for automation according to the judgement dexterity framework in Figure 17.

		Dexterity	
		High	**Low**
Judgement	**High**	Dedicate Human Capital	Standardize and Automate
	Low	Simplify and Automate	Automate

Figure 16: The Judgement Dexterity Framework for Automation

For Company X, the major areas of focus include clean and deburr, machine loading, inspection, and quoting and programming.

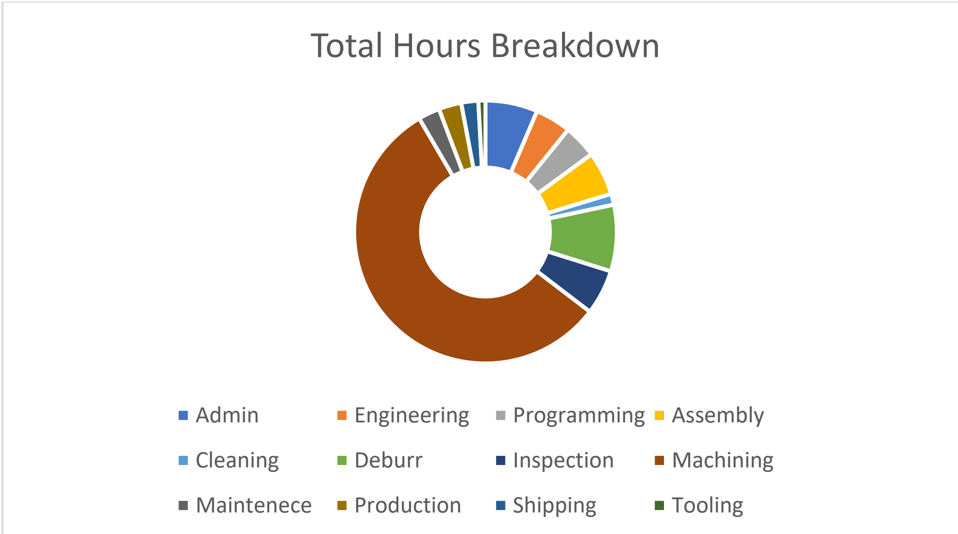

Figure 17: Breakdown of hours by function at Company X[2]

7.3.1 Automate Non-Machine Steps

Tools: Robotics and Automation, Quality at Source, Setup Time Reduction

Behaviors Fostered: Drive, Customer Focus

Parts that are machined in a job shop need to be deburred and inspected at least once. These processes are time-consuming and tedious. At Company X, deburring accounts for about 10% of the total paid hours. Inspection accounts for about 6%. Because these processes are required across all parts, work builds up at each one of these work centers, often causing a bottleneck.

Most job shops use a Coordinate Measuring Machine (CMM) to ensure the geometry and dimensions of the part match the design specified by the customer. Before the part can be measured, a program for the CMM must be developed by the inspection team so that errors can be identified. Once the program is complete, the team must carefully set up and run the inspection on the part. This is a very time-consuming process that each part goes through.

[2] Source: Company X labor hours in 2019

The CMM is a very reliable inspection tool, but it does not support high levels of productivity throughout the shop. In a busy job shop, when a part is finished on a machine, the machinist takes down the old job, and sets up the machine for the new one. The parts are taken to inspection where they sit in a queue to be checked. Typically, setups take several hours to several days. If the part was incorrectly machined and rejected by the CMM, it must be reworked. The machinist will have to wait for the machine to finish the new job, or interrupt the existing job. This results in one or two additional machine set ups, which in some of the most extreme cases, can take longer than the time it takes to run the part. This causes delays that impact material flow throughout the shop.

One solution to this problem is that measurement probes can be installed on the CNC machines to conduct in-process inspections. The probes help the machinists catch major errors early in the machining process. While the CMM machine may not be replaced altogether, the team can reduce the number of parts that need to be measured, and to reduce likelihood of failure by checking the part during the machining process.

Like inspection, deburring is often done once the machining has been completed. Deburring is a tedious, time intensive task. Instead of having all the deburring done manually, machine tools can be programmed to deburr most or all edges on a component while it is still in the machine.

While adding inspection and deburring to the in-machine process can increase the per part cycle time, the total time required to complete the job on average will decrease. The job duration will be more predictable as the likelihood of rework or excessive wait times prior to inspection or deburr will be eliminated.

7.3.2 Automate Machine Loading

Tools: Robotics and Automation, Setup Time Reduction, Standard Work

Behaviors Fostered: Drive, Customer Focus

Setting up a job and switching parts requires both judgement and dexterity. The location of the part and the fixture, relative to the tools in the machine must be set up with a high level of precision. This means that there is a lot of internal processing time required, and during this internal processing time period, the machine must be stopped to perform the setup. Furthermore, it requires attention from the operator every few seconds, minutes, or hours to make sure the changeover from part to part is done correctly.

Rather than having the part loading and fixture setup done at the machine, job shops can use a standardized pallet. The pallet is a movable interchangeable part of a machine tool to help transport parts into or out of the machine. Because the pallet is standardized, it can be loaded into the machine with a high level of precision and accuracy. Part specific fixtures can be set up on the pallet by the operator outside of the machine. Furthermore, each job can have multiple pallets, so that when a part is being machined, the next part can be loaded, eliminating machine downtime. For frequently run parts, the pallets can remain set up, essentially eliminating the setup time.

Once the machines and pallets are standardized, the loading and unloading can be automated. When a new part is ordered, fixtures can be made to fit the pallet, and the pallet can then be loaded into a pallet loading system. The pallet loading system will serve as a central repository for pallets for upcoming jobs. Before the current job finishes running, the pallet for the next job will be pulled from the inventory system and staged for material loading. When the material is loaded, the operator would know the location of the material relative to the fixture, the fixture relative to the pallet, and therefore relative to the pallet. Once the material is placed in the fixture, the pallet can be staged for loading into the machine. When the current job is complete, the pallet will be transferred out of the machine automatically. The finished part can be unloaded either by an operator or a robot, and the pallet can then be returned to the pallet inventory. The new pallet can be loaded into the machine. Because the pallet is standardized, the movement of the pallet requires no judgement or dexterity. The process for loading and unloading the pallet does not change, making it possible to know exactly where the pallet is with respect to the machine once it is loaded. Since the location of the part to the pallet is known, the location of the pallet to the machine tells us with high precision, the location of the part to the machine. This enables unmanned machining, as the pallets can be set up in advance.

Once the shop is fully digitized, the pallet loading and inventory system can be connected to the ERP system. The system can output a schedule and direct each pallet to each machine automatically. Highly skilled operators can focus on building fixtures and improving machine programs, while less skilled operators can focus on setting up fixtures or loading and unloading parts.

The system minimizes human error that results from differing setup techniques. It also maximizes machine utilization, as the machine can run minimal human intervention. The reduction in variation through standardization can improve quality, and the unmanned machining can reduce lead times. Increased quality and decreased lead time reduce cost, providing value to the customer.

7.3.3 Automate Quoting and Programming

Tools: Robotics and Automation, Digitization

Behaviors Fostered: Drive, Customer Focus

In a job shop, quoting and programming are business critical tasks that require highly skilled and experienced resources. Each time a customer wants to purchase a part, a request for quote (RFQ) is sent to the job shop. The job shop must estimate the cost and lead time to produce the part, and subsequently return the estimate to the customer in a timely manner. The customer will send out RFQ's to several job shops, looking for the best price, lead time, and quality.

Typically, job shops will have their most experienced members in charge of quoting. The quoting team will review part drawings to approximate the labor and materials necessary to produce a part. A very rough routing for the part is discussed, but specific machine requirements are ignored. It is not uncommon for the quoting team to have too many quotes to review, and it typically expects only about 20% of those quotes to materialize into orders.

The quote won by the shop must be programmed. Each programmer uses their own method to develop the final router for the part, as the rough routings developed by the quoting team typically never make it to the programmers. This leads to tool and process proliferation which drives complexity on the shop floor.

Once the part is programmed, the expected machine requirements are known, and the part can be scheduled on the machines. The team preview the machining process and cycle times. In many cases, more than half of the quoted lead time is used up just to push the part through the programming process, leaving the team under pressure to free up machines to process the part and deliver on time.

To alleviate the pressure on the production team and reduce the programming lead time, the shop can develop part families and standard machining practices to streamline the quoting and programming of parts. As products are grouped, they can be processed using proven techniques. The quoting team will know with higher confidence the expected margin on a job. Furthermore, the programming team will be able to program the process quickly, because they will have done it many times before.

As the processes are standardized, they can be automated. The customer can send over a Computer Aided Design (CAD) model of their part that is fully defined, specifying the material, dimensional tolerances, and special processes. Using data from past jobs, a quote can be generated automatically, giving customers instant feedback on manufacturability, expected cost, and lead time.

The fully defined model can be imported into Computer Aided Machining (CAM) software where the toolpaths can be generated automatically by pulling proven toolpaths developed to machine similar features on similar parts. The CAM software can then simulate the machining to check for any errors. The program can be reviewed by a programmer to ensure it is ready for production.

The automation reduces the load on the programming and quoting team, and drives predictability on cost, lead time, and quality. The team can provide shortened lead times as they will have a clear view of capacity requirements from the moment an RFQ is sent over by a customer. The program will be developed in a matter of hours, down from several months, further reducing cost and lead time, driving value for the customer.

Chapter 8

8 Results

The operational excellence strategy was deployed at Company X. This section highlights the impact the strategy had in the early stages of execution as the company worked through strengthening the foundation and synchronizing operations. It then explores the expected gains at Company X as they continue to execute the strategy and build the factory of the future.

8.1 Initial Results

Company X saw improvements across several different performance metrics. The team saw quoting volumes increase by 43% from 2019 to 2020. While quoting volume alone does not guarantee future sales, the team maintained their quoting win rate. This increased their backlog, a measure for orders booked by customers, to record levels. During the research, the team saw the trailing twelve-month backlog levels grow by 1.5 times what it was at the start of this research.

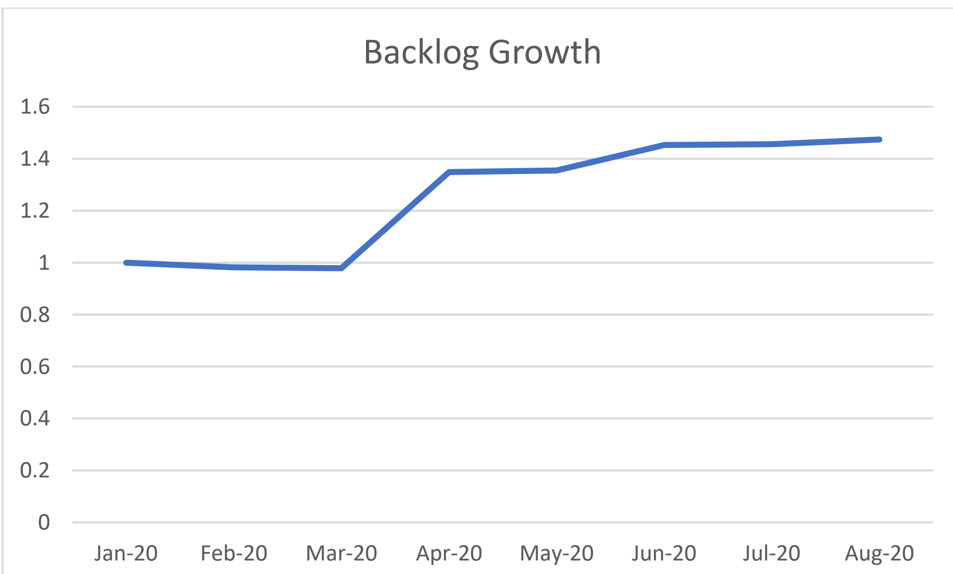

Figure 18: Company X Backlog Performance

One of main the drivers of backlog growth came from the companys on time delivery performance improvements. The team improved their trailing twelve month internal on time delivery performance from 58% to 70%. The internal on time delivery measure ignores any changes the customer makes to the original promised date after the initial sales order is placed.

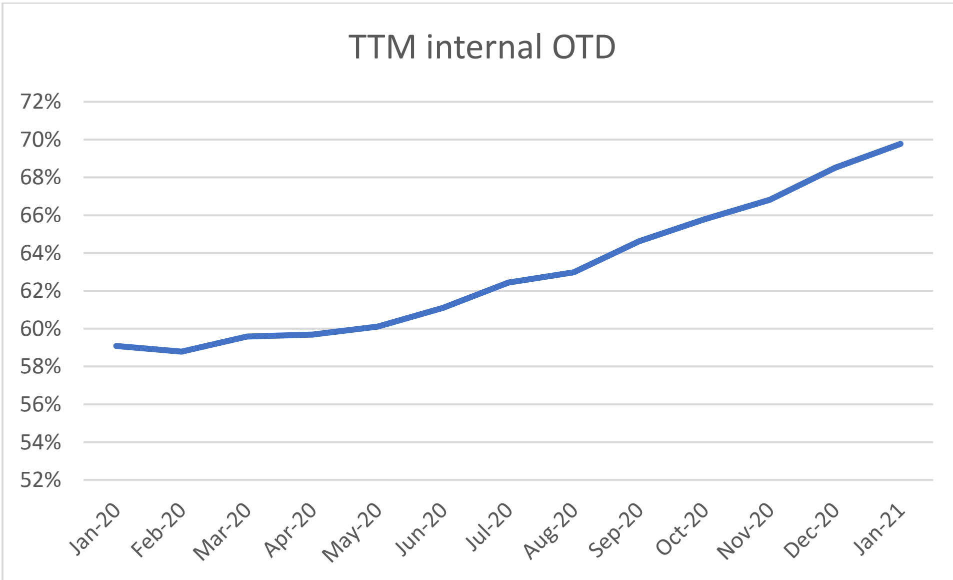

Figure 19: Company X Trailing Twelve Month Internal On-Time-Delivery

More notably, the team increased their monthly external on time delivery performance from 50% to 96%. The external delivery measure is based on customer measured performance.

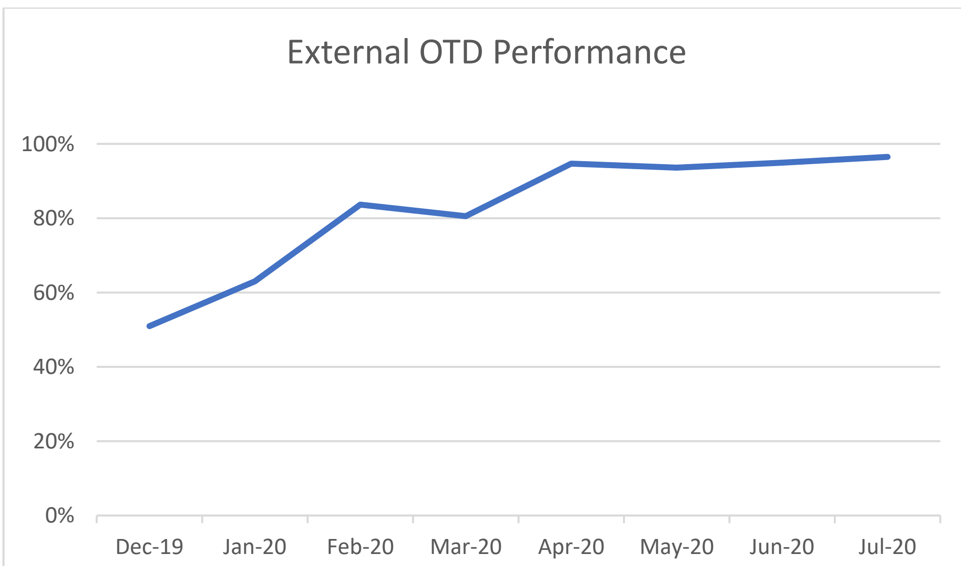

Figure 20: Company X External On-Time-Delivery Performance

In addition to improve on time delivery performance, the team steadily increased trailing twelve-month revenue.

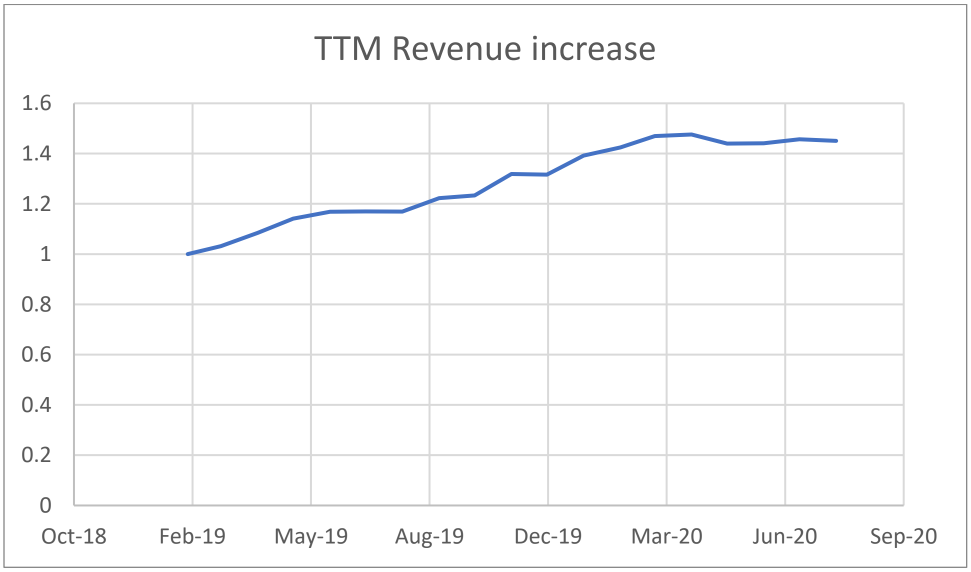

Figure 21: Company X Trailing Twelve Month Revenue Increase

Furthermore, the company increased trailing twelve-month margins, suggesting the operational improvements outlined in the strategy were supporting a continued decrease in manufacturing costs.

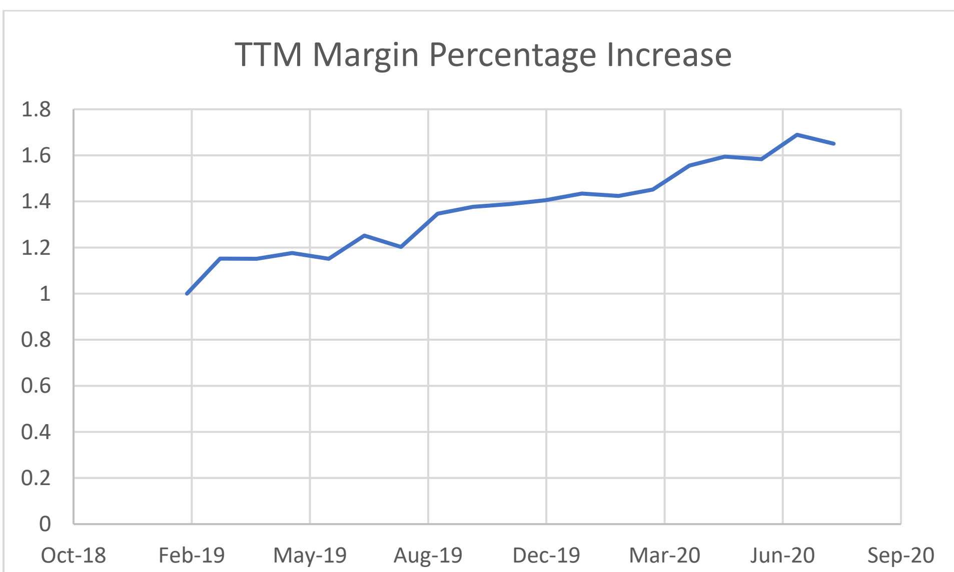

Figure 22: Company X Trailing Twelve Month Margin Percentage Increase

The initial results are staggering, but only capture the impact of improvements from the early stages of the job shop transformation strategy. Company X focused primarily on strengthening foundation and began executing initiatives in synchronizing operations during the tenure/course/time period of this research. The company is on a glide path to future operational excellence as they maintain focus on their key value drivers, and continue to work to build the factory of the future.

8.2 Expected Impact

To depict the expected impact of the strategy on Company X, the company's expected gross margin improvement by each phase of the job shop transformation strategy was modeled. Decreased gross margins, alongside perfect quality and on time delivery imply that Company X has created value in the form of better products, made faster, for a lower cost.

Company X's expected five-year gross margin improvement by strategy phase is shown below. The greatest realization of cost reduction comes from synchronizing operations and building the factory of the future. Not all the initiatives will go as planned, and some of the anticipated reduction in costs will be unrealized. The wedge represents the improvements that are never realized. Through continued execution to the strategy, Company X expects a 10% gross margin improvement in the next five years.

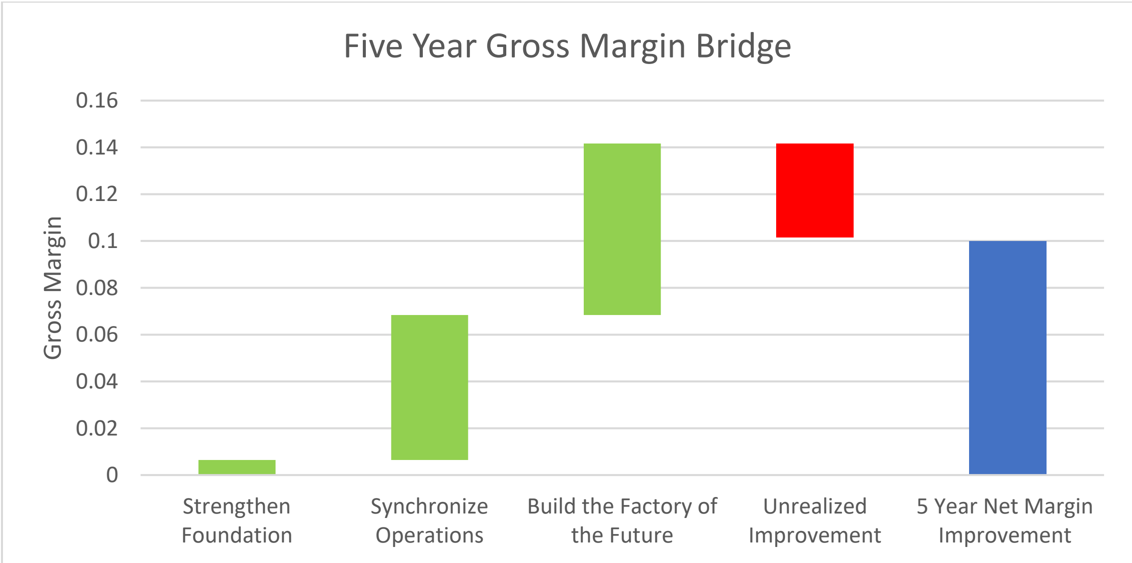

Figure 23: Company X Five Year Gross Margin Bridge by Strategy Phase

Looking at each initiative over the next five years, the greatest improvements will come from the full implementation of automated production engineering two years after the company began their transformation. The next most important contributions come from capacity planning and scheduling initiatives in the synchronizing operations phase of the strategy. As shown in the chart below, the improvements build over time, leading to a potential for over 15% gross margin improvements in five years, 5% of which is estimated to go to unrealized improvements.

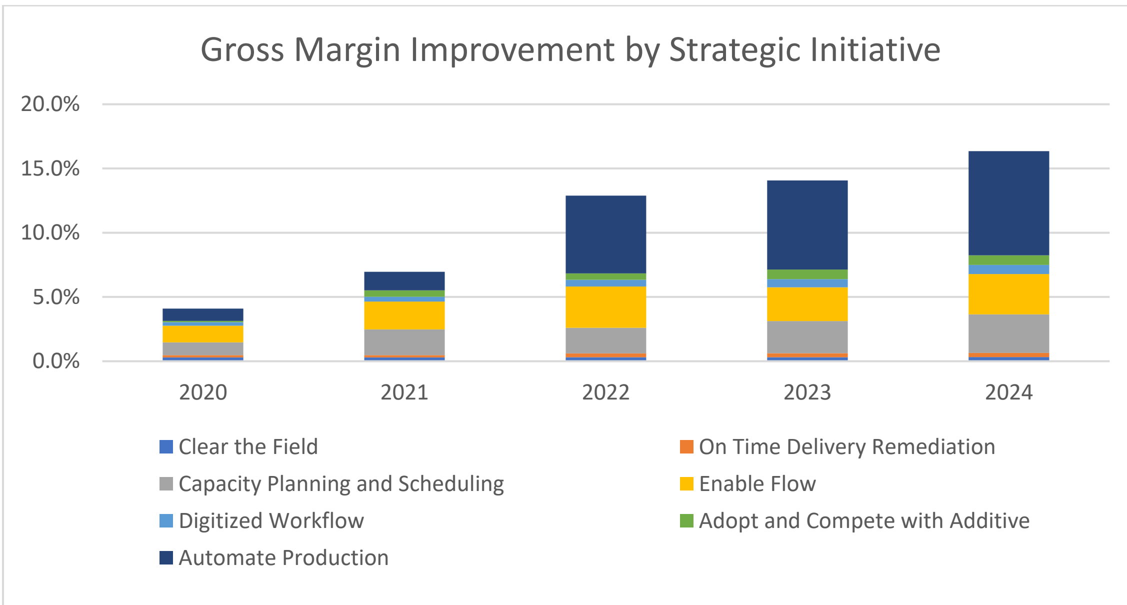

Figure 24: Company X expected Gross Margin Improvement by Strategic Initiative[3]

To maintain progress to the goal, an eight-quarter outlook is used to tie each initiative to expected margin improvements, specific capital and operations expenditures, and the leading and lagging metrics that will support continued progress towards the key value drivers.

[3] Company X Gross Margin Improvement was estimated by identifying the expected efficiency gain from each initiative over the next five years. The efficiency gain was translated into a cost savings using the cost of each resource. The cost savings was translated to gross margin improvement by dividing the projected revenue for the corresponding year.

The table below outlines the expected margin increase from each initiative. Here, the expected margin increase was calculated using the expected cost savings from the initiative in that quarter, and the expected sales for that quarter.

Table 11: Eight-quarter outlook framework example for Company X

		2021		2022
		Q1	**...**	**Q4**
Gross Margin Improvement	Clear the Field	0.10%		0.10%
	On Time Delivery Remediation	0.10%		0.10%
	Strengthen Foundation	0.20%		0.20%
	Capacity Planning and Scheduling	0.50%		0.50%
	Enable Flow	0.25%		0.75%
	Synchronize Operations	0.75%		1.25%
	Digitized Workflow			0.10%
	Adopt and Compete with Additive			0.10%
	Automate Production			2.50%
	Build the Factory of the Future			2.70%
	Gross Margin Improvement	0.95%	...	4.15%
Capex and Opex	Clear the Field	0.1		
	On Time Delivery Remediation	0.1		
	Strengthen Foundation	0.2		0
	Capacity Planning and Scheduling	0.1		
	Enable Flow			
	Synchronize Operations	0.1		0
	Digitized Workflow			
	Adopt and Compete with Additive			
	Automate Production	0.1		
	Build the Factory of the Future	0.1		0
	Total Capex	0.4	...	0
Metrics	Leading: 3 Day Machine Schedule (% Predictable)	85%		100%
	Leading: Fixture Hours (% Reduction)			75%
	Leading: Setup to Run			3%
	Lagging: Machine Production Hours (% Increase)	5%		3%
	Leading: On Time Starts	90%		100%
	Lagging: OTD	95%		100%
	Lagging: Revenue predictability	85%-115%		90%-110%
	Leading: Earned vs Paid	90%		110%

In the example above, Company X expects to gain a 0.50% improvement from capacity planning and scheduling and 0.25% improvement from enabling flow, summing up to a 0.75% margin improvement from synchronizing operations in the first quarter of 2021. The contribution from enabling flow is expected to increase to 0.75% as setup time reductions, and other projects used to enable flow maturation. This results in a 1.25% margin improvement from synchronizing operations in the 4th quarter of 2022.

The gross margin improvement represents a lagging indicator. To achieve the increase in gross margin on a quarterly basis, the levers that can be pulled by the team to drive the improvement in gross margin must be identified. For example, the team must lock in a 3-day machine schedule with 85% predictability by the first quarter of 2021 to achieve the 0.50% gross margin improvement expected from capacity planning and scheduling initiatives. Additionally, the table outlines the capital and operational expenditures required on a quarterly basis. This allows the team to predict spend on a quarterly basis and ensure that the investments they are making pay off.

This table ensures the team maintains progress across all strategic initiatives. Each quarter, the leadership team can review predictions from the prior quarter, make any course corrections to the remaining seven quarters, and develop predictions for the eighth quarter.

Chapter 9

9 Accelerating Through a Crisis

The Chinese word for crisis contains two symbols, the first translating to “danger”, and the second translating to “opportunity”. A crisis represents a critical juncture where one path leads to success and the other path leads to failure. During this research, the COVID-19 pandemic hit. The pandemic would make or break businesses throughout the world. This section describes the process that enabled Company X to accelerate through the crisis, emerging stronger and more resilient.

9.1 Do the Right Thing

When faced with a crisis, the leadership team will have to make difficult decision that balance tradeoffs. Leadership has the responsibility to support the needs of the employees, customers, and shareholders. In the case of the COVID-19 pandemic, the most pressing issue was the safety and wellbeing of the employees. Company X, like many organizations depends on their employees to produce product for their customers, which in turn provides strong financial results for their shareholders. In times of uncertainty, it is difficult to know the best course of action. Rather than trying to optimize a bad situation, focus on doing what is right. When the safety and wellbeing of their employees was at risk, Company X chose to shut down the plant and send employees home for a week with full pay. In the short term, this was costly for the company. However, this decision gave the leadership time to develop a safe operating plan that minimized risk for employees. More importantly, it fostered trust between the employees and the leadership. While shutting down a plant was not something the leadership team wanted to do, it was an opportunity to do the right thing, and doing the right thing pays off. For Company X, this decision showed their employees that the new leadership cared about their wellbeing and could be trusted, something that would have otherwise taken years to develop.

9.2 Communicate

Doing the right thing must be coupled with high levels of communication. A crisis creates constantly changing circumstances. Change invokes discomfort, anxiety, and concern. Leaders must maintain direct lines of communication with their employees, customers, and shareholders to reduce these feelings so that the team emerge from the crisis.

Communication should be done with urgency, clarity, competence, and honesty. Urgency is important because quick communication tells your stakeholders you are prepared to respond. If you do not communicate with your team quickly, even if you have taken action to mitigate the impact of the crisis, they will not know and will assume you are not responding. Clarity gives the stakeholders the relevant facts. Leadership should consider their audience and develop a clear message that addresses what is most important to the group. Competence is vital for the team to build confidence in the leadership. It is important that leadership communicates in a way that shows they are capable and have the means to dealing with the situation at hand. Honesty is crucial for trust. Leadership should be open and honest about what they do and do not know as it relates to the crisis. It is better to be transparent and admit you do not have all the answers, than to cover up the magnitude of the situation.

Company X had strong communication with their employees, customers, and shareholders during the pandemic. Each day of the shutdown, the leadership held a mandatory daily conference call with all employees. During the call, the employees were given timely updates on the reopening process. While no one on the leadership team was a doctor or infectious disease expert, they built credibility by using CDC guidance to inform their decisions about how to respond. The leadership was honest about their own lack of expertise on the matter, but referred to expert guidance to ensure they did what was right. On the call, the team opened the line to questions so that everyone's concerns could be addressed.

In addition to daily employee conference calls, the leadership team contacted each customer to notify them of the shutdown. They communicated the expected impact on operations, and set up additional time to work through a more detailed review of any part delays. The leadership team also met with the board daily to provide an update on the expected financial impact of the shutdown. Each day the team could better estimate the impact of the shutdown, and those updates were relayed to the shareholders.

9.3 Get Ahead and Stay Ahead

The goal in a crisis is to transition from the crisis managing you, to you managing the crisis. Shutting down before being forced to shut down gave Company X a chance to get ahead. The team developed a minimum exposure staffing and manufacturing recovery plan. They created new shifts, transitioning from a two-shift schedule where employees worked either five eight-hour days, or five eight-hour nights, to a three-shift schedule where employees worked either four ten-hour days, three twelve-hour days, and five eight-hour nights. All employees were given their preferred shift and were notified of their new schedule with a personal phone call. The leadership, together with a group of volunteer employees developed new operating procedures governing daily work. Upon return to the workplace, the new operating procedures were reviewed each individual employee. The leadership reminded each employee of the importance of taking extra precautions during this time. The new shifts and operating procedures made it so that any outbreak could be contact traced eliminating the need for another full plant wide shut-down.

As soon as the plant was reopened, the team notified customers and provided updates on specific parts. They also set up daily touch-base to assess new operating model and make changes as new information and guidance was available. The team also conducted a response plan to ensure the Company would remain competitive following pandemic. With the sharp decline in commercial travel, the team expected to see more competition in defense. Therefore, an assessment and action plan were developed for order bookings, delivery, and cost. For order bookings, a revenue potential sensitivity analysis was conducted on existing customers to understand if revenue expectations for 2020 need to be adjusted. For delivery, an analysis on the disruption to delivery caused by new operating model and shutdown was conducted, and an action plan developed. For cost, the team assessed potential earnings compression due to additional cost projections. Furthermore, a capital expenditure and expense control review and mitigation plan were developed.

These actions helped Company X stay ahead of the crisis. The leadership team, despite working through extremely challenging times, watched as order bookings increased, on time delivery performance improved, and costs declined. Employee engagement and company pride also improved. Other local job shops went through shut downs and layoffs as the crisis managed them. Company X grew, as they managed the crisis.

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Chapter 10

10 Conclusions

A focus on the key value drivers, combined with a well-defined strategy and execution function, enabled Company X to clear the field, secure the foundation, and create a strong base for future success. The team will continue to synchronize operations and build the factory of the future. leveraging tools that are applicable to high mix low volume manufacturing environments.

The framework used to transform operations is not unique to Company X, only the specific details are. Any job shop can follow the steps outlined in this thesis to begin their transformation journey. The journey begins as the job shop confirms their value drivers and checks their strategy against the value drivers. In parallel with the strategy development, the team develops their execution function to enable progress and foster a culture of continuous improvement. The first stage of the journey is when the job shop addresses the most immediate needs including any gaps in on time delivery, safety, and quality. This helps the team secure the foundation and develop behaviors that support self-sustaining progress. With a strong foundation, the team can begin to transition into the second stage of their journey. Here, the team will focus on synchronizing operations to reduce lead times and decrease costs. As the job shop achieves synchronization through increased visibility and alignment across all information flows, they can build the factory of the future, accelerating beyond their competition to deliver exceptional value to their customers.

As seen with Company X, there is overlap in the tools used to drive operational improvements in both a highly variable job shop environment and a production environment. However, the applicability and ease of implementation will differ. The table below provides the final assessment of tools reviewed for the high mix low volume manufacturing environment as part of this research.

Table 12: Applicability and Ease of Implementation of Tools in Production and High-Mix Low-Volume Environments

		Production		**High Mix Low Volume**	
		Applicability	Ease to Implement	Applicability	Ease to Implement
	Process Mapping	●	●	●	●
	Gemba Walks	●	●	●	●
	5S	●	●	◕	◑
	Standardized Work	●	●	◕	◔
	Visual Controls	●	◕	◕	◑
	Setup Time Reduction	●	◕	◕	◔
Lean	Quality at Source	●	◕	●	◔
	Backwards Scheduling	●	●	●	◑
	Optimization	●	●	◕	◔
Other	Demand Planning	●	●	●	◑
	Robotics and Automation	●	◕	◕	◔
	Workflow Digitization	●	◕	◕	◔
	Additive Manufacturing	◑	◑	●	◑
Industry 4.0	AI and Predictive Analytics	●	◑	●	◔

Research suggests that lean tools that apply to production environments are generally applicable in the job shop, but must be implemented with special considerations. Process mapping and Gemba walks are highly transferrable. 5S, while an extremely valuable process, must be implemented with great care. Work in a job shop requires a diverse set of tools to manufacture custom parts. It is more important to give employees a bit of freedom in organizing their workstation, knowing that the tools required today will differ from the tools required tomorrow.   Similarly, standard work must be applied to common processes across parts to drive efficiency, but must be developed in ways to ensure applicability and adherence to the various products manufactured in the shop. Visual controls, setup time reductions, quality at source should also be introduced using the same lens. The lean tools are critical to achieve operational excellence, but must be introduced thoughtfully to reap their benefits.

The other operational tools commonly used in production environments, that are applicable in the job shop environment are backwards scheduling, optimization, cross training, and demand planning. Backwards scheduling, while highly applicable, can be difficult to implement because job shops struggle to have highly predictable run times or processing times. The team make assumptions around how long the machining, or outside processing of a new part will take. They must start early enough to ensure they have time for unexpected delays, but not so early that run their backlog down or increase the level of WIP in the shop. Optimization, while highly valuable for job shop scheduling, is extremely hard to implement due to the complexity of operations. The job shop scheduling problem is an NP-hard problem. Heuristics must be used in combination with optimization techniques to develop a solution that can be used by the shop. While this is an opportunity for job shops to take production to the next level, it should be done after the simple approaches have been used to achieve near optimal solutions. Demand planning is very useful for job shops, especially when planning out long term capacity requirements. It can be difficult to predict customer orders due to the highly customized nature of work, however the team should work closely with their customers to identify future work, and plan out material, labor, and capacity requirements on a larger scale.

Industry 4.0 tools can accelerate job shop performance, but only if applied correctly. In high volume production, it is easier to introduce robotics, transfer to a digitized workflow, and leverage predictive analytics because the same product is being produced millions of times. In the job shop, robotics and automation must be applied to the processes that are similar across different products. Furthermore, they must focus on the low judgement, low dexterity work, which can be difficult to immediately identify. Implementing automation requires looking at the shop through a new lens; one that focuses on overall lead time reduction, minimizing setups and other processing steps, rather than per part cycle time reductions, which cannot be transferred and applied easily. Workflow digitization is also highly valuable, but can be difficult to implement. Additive manufacturing is both a threat and a potential benefit for job shops. It is a source of competition but can also support decreased lead times through faster fixture development. Finally, AI and predictive analytics can support automated programming and quoting in the future. It extends the digital thread to traditional manufacturing, supporting a shift from the traditional analog process to a digitally native process. This shift would create unparalleled levels of value for the job shop by enabling teams to deliver high quality parts, weeks or even months faster than the competition. The challenge for job shops is developing a dataset that can be used to develop automated solutions.

The tools reviewed should be deployed through the three-phase process described in this research. First, the team must strengthen the foundation, creating a strong base for future success. Next, the team must synchronize operations, driving efficiency through the alignment of information, product, and people flows. Finally, the team must build the factory of the future, using technology to transform traditional manufacturing into a digitally native process. The specific initiatives for the job shop will support the value drivers for the company, and each initiative will be deployed through the execution function that introduces a culture of continuous improvement.

Company X is breaking the mold on the job shop. It will become the industry standard for precision machining supply. Using the framework established in this research, your job shop will too.

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