Abstract

Lean production began as a new method for creating value through the elimination of waste, continuous process improvement by workers, and fostering respect for people. Despite its success in other industries, the significantly lower production volume, the substantially higher complexity, and the service-oriented nature of aviation maintenance demand significant adaptation of Lean principles to be effective. The lack of a holistic study on Lean adoption for aerospace production and aviation maintenance organizations hinders transformation as the two industries are intertwined in product and characteristics. Lean adoption in aerospace production is hindered by the lingering notion that it is an “automotive idea,” the context of the production plant, and management’s focus on short-term goals rather than the long-term transformation of the plant. Integrated product teams are indispensable as they can accelerate the transition between development and production, and most importantly, bridge the gap between production and maintenance operations. Maintenance, repair, and overhaul organizations use Lean techniques to reduce overall maintenance costs, lower aircraft turnaround times, and improve productivity. The emphasis is placed on optimizing in-house areas with direct product interaction, such as the shop floor, as optimizing the value stream by incorporating the significant unscheduled maintenance demand into the work schedule greatly impacts resource utilization. Surveying the success stories of Boeing, Lufthansa Technik, and FedEx Express has revealed that Lean adoption requires collaboration between all stakeholders: production, service, customers, and education.

Keywords: Lean, aerospace production, aviation maintenance, integrated product teams, culture transformation, production plant context

Introduction

Following the publication of Womack et al.’s (1990) work The Machine That Changed the World, Lean manufacturing was popularized and quickly superseded mass production in the automotive industry. In the past three decades, other industries such as fast-moving consumer goods and construction have also adopted Lean principles with great success. There are immense possibilities for Lean implementation in the aerospace and aviation industries, but the automotive and aerospace industries have very different production requirements and characteristics. Since the aerospace and aviation industries have a significantly lower production volume and substantially higher complexity when compared with most other goods, they demand significant adaptation of Lean principles to be effective. Additionally, Lean adoption in the
aviation industry deviates significantly from the traditional, manufacturing-centric approach due to the different educational backgrounds of industry professionals, certification requirements, and its service-oriented nature. While industry-specific conditions can pose hurdles to Lean implementation, the character of individual production plants such as company culture, employee training, and characteristics of customer demand can also make a significant impact on whether the transformation will be successful.

Lean transformation within the aerospace industry has been limited in the last few decades, and mostly confined within larger organizations. The unique challenges within the aerospace and aviation industries are often evaluated independently in the existing literature. This segmented approach is problematic as choices made during an aircraft’s design and production phases often directly impact the work done by maintenance technicians. The lack of existing literature evaluating the factors affecting Lean adoption for aerospace production and aviation maintenance holistically poses a challenge for those who wish to streamline their organization’s operations. This literature review intends to discover the reason behind the slow adoption of Lean principles in aerospace manufacturing and aviation maintenance organizations. Additionally, this review will also identify factors affecting the success of Lean transformations and study successful Lean implementations in manufacturing and maintenance. This level of understanding can be achieved through surveying published works on Lean implementation in product development, production, supply chain, maintenance, and education.

**Lean Adoption in Aerospace Production**

Lean manufacturing, a derivative of the Toyota Production System, can be summarized as a systematic approach for creating value through the elimination of waste, continuous process improvement by workers, and respect for people (Liker, 2004, p. 6). Despite its success in the automotive industry, the adoption of Lean in aerospace production requires a unique implementation. The industry has highly differentiated and hugely complex products, comparatively low production volumes, and low repeatability, making difficult the direct implementation of the lessons learned in the automotive industry.

**Motivations and Difficulties in Implementation**

The motivation for aerospace companies to pursue Lean falls under five categories as per Amrani and Ducq’s (2020) study: market demand, product diversification, product complexity, safety focus, and creating an agile supply chain (p. 1313). Despite the benefits of adopting Lean far outweighing its costs, only a few large aerospace manufacturers had documented Lean initiatives before the 2010s.

The aerospace industry’s transition to an economy of higher-volume production, continually increasing complexity, and the diversity in customer demand all drive smaller aerospace suppliers to embrace Lean (Amrani & Ducq, 2020, pp. 1315–1320). The difficulties in aerospace Lean implementation are threefold: the lingering notion that it is an “automotive idea,” the context of the production plant, and management’s focus on short-term goals rather than the long-term transformation of the plant (Crute et al., 2003, p. 917).

The first difficulty can be summarized by the “not invented here” syndrome, but this can be combated by piloting Lean initiatives in an underperforming department, and allowing the changes to permeate from there to the whole site over time is preferable over a rigid, top-down, management-driven Lean initiative (Crute et al., 2003, pp. 921–922). The bottom-up approach is proven to be an effective change strategy and can impact company culture from within. It allows the people who are adding value to the product to affect their organization from within, challenging the outsider narrative of the idea’s origin.

Another difficulty for Lean implementation stems from the management role at the production plant level, rather than sector-specific factors. In a traditional mass production facility, employee training is reduced to a minimum and they are considered replaceable (Womack et al., 1990, p. 31). A mass production mindset hinders Lean transformation as it contributed to the historical lack of employee education in factories. Only a handful of suppliers had formal employee training programs in place. That is cited as one of the reasons behind the lackluster supplier Lean transformation in Michaels’ (2010) large aerospace company case study, in addition to the lack of performance metrics and the lack of continuous improvement programs at that level. Besides, customers viewed Lean as merely another buzzword-filled corporate “fad” with no impact on product quality, and poor communication drew attention towards early failures rather than later successes (pp. 137–140). The workers’ replaceability in a mass environment attempting to transition also made them perceive Lean initiatives as a threat to their livelihoods rather than a way to increase productivity. Due to the cyclic nature of the aerospace industry, any slight economic downturn will often lead to tens of thousands of jobs being lost due to canceled orders and deferred deliveries (Jolly, 2020).

Management’s desire for “quick wins” will often lead to premature termination of Lean initiatives, but supportive management is required to let the initiatives come to fruition. It took three years for 30% of Michaels’ large aerospace company machining suppliers to understand Lean, with only less than 10% of the sub-tier suppliers implementing it. The author believes it takes at least nearly a decade to implement Lean effectively—two years for basic understanding, three to four years for training and implementation, and two to four more years to achieve
sustaining skills and behaviors, with patience being key to successful Lean implementation (Michaels, 2010, p. 144). Toyota took nearly three decades to perfect its business processes and to build a corporate culture conducive to Lean (Liker, 2004, p. 23). Despite the challenges with implementation, the companies that embraced it with full managerial support continued to prosper in an increasingly competitive market.

It is believed that Lean will bolster the competitiveness of companies as it allows them to “meet and respond as swiftly as possible to the changing [market] environment” (Garre et al., 2017, p. 8440). Additionally, Lean will also allow companies to produce and supply high-quality products at a reduced cost as demanded by customers. Studies indicate that SMEs—small and medium-sized enterprises—have different focuses on implementing Lean when compared with larger firms. SMEs typically regard Lean as a method to meet the “growing demands of their customers and to remain profitable in an increasingly competitive environment” (Garre et al., 2017, p. 8441). This mindset is in contrast with that of larger firms, which use Lean as means to refine their core activities as they form strategic alliances and partnerships (Lee & Oakes, 1996, p. 197). Through studying three SMEs, Crute et al. (2008) concluded that their Lean transformations made significant impacts on quality, cost, and delivery metrics. One company achieved a “33% reduction in focus part manufacturing time,” and another increased their production volumes from 60,000 to 140,000 parts per month (pp. 3–4). The third company improved its on-time delivery performance from 15% to approximately 85%, and all three companies increased their profits through implementing Lean despite the early investment required (Crute et al., 2008, p. 6).

Integrated Production Teams

As aerospace production increases in volume due to the proliferation of both civil and military aviation, integrated product teams—multidisciplinary groups working together to build successful programs—are indispensable as they can accelerate the transition between development and production. Lockheed Martin Aeronautics declared 1999 the “year of Lean” and began applying Lean techniques on three projects: F-16 Fighting Falcon fighter, F-22 Raptor fighter, and C-130J Super Hercules military transport aircraft. The three projects were in very different stages of their respective product life cycles, which allowed the company to gain insight into different applications of Lean implementation in parallel (“Leaning Forwards,” 1998). The F-16 had been in continuous production for over two decades at Fort Worth, Texas, and the F-22 was still in its engineering and manufacturing development phase. The C-130J is a major upgrade to the original C-130 design from the 1950s, and the first J-variant was delivered to the Royal Air Force in 1999. The parallel approach helped Lockheed discover opportunities to eliminate huge amounts of waste within its product development and production value streams, albeit with a top-down, management-driven program (“Lean Stories,” 1999).

Across the Atlantic, BAE Systems, another major defense contractor, “perceives that the aerospace industry is 10–15 years behind the automotive sector in implementing Lean ideas” (Crute et al., 2003, p. 918). BAE Systems embraced Lean at their Samlesbury factory to control costs for the multinational Eurofighter Typhoon project as the end of the Cold War led to a significant reduction in defense spending. The Eurofighter consortium pioneered a new “right-first-time” culture, with integrated design teams responsible for sections of the aircraft from design to customer support rather than the traditional task-oriented organizational structure, a first in multinational aerospace projects (Hoyle, 2007). The vertically integrated structure of the project group resources is based on sections of the aircraft rather than functional silos, and it effectively leverages the core competencies of each company within the consortium. This structure allows them to deliver greater quality on the first pass and increased team accountability as cross-functional teams foster improved communications and collaboration between teams (Flores et al., 2015, p. 19).

Factors Affecting Lean Adoption

The model in Figure 1 showcases the different factors contributing towards a successful Lean transformation. The factors placed within unshaded rectangular boxes are external to the group responsible for Lean adoption, and the factors in ovals are factors internal to the group. The interactions between different factors that contribute towards Lean production adoption are indicated by the various arrows. Major factors affecting Lean adoption can be broadly organized into three groups: trigger, control, and success (Martínez-Jurado & Moyano-Fuentes, 2012, pp. 339–341). The trigger factors—typically external—are what drive a company towards considering Lean adoption, and both manufacturing plants and corporate management must be convinced about Lean’s growth potential for it to be successful. The control factors are limitations to the existing factory organization that may make or break the Lean transition proposed by management. If workers’ concerns are not properly mitigated, they and the Union may see Lean transition as a threat to their livelihood rather than a way to reduce waste. Without workers’ support, any attempts to transfer decision-making powers closer to the work will be futile as they will not act in the best interest of the company. The ability to make proper decisions can be fostered through providing adequate training on visual management and practical problem solving (Flores et al., 2015, p. 24). The success factors are the foundation
required for effective Lean implementation, and it requires support from within the company, a shift in corporate culture, and most importantly, a leader that can convince others in the organization that change is needed. To understand what is needed to successfully implement Lean, a company must first conduct an honest self-assessment before making any significant investments (Brown & Hassold, 2020). Unless stakeholders understand how Lean can improve their business and operations compared with the status quo, they run the risk of multiplying their investment with little return.

Martínez-Jurado and Moyano-Fuentes (2012) studied five production plants under the EADS consortium—two final aircraft assembly lines and three manufacturers/assemblers—with varying levels of Lean implementation. Before consortium-level Lean adoption in 2007, customer demand and industry rivalry had driven Lean transitions at three of the five survey sites. Collaboration between design and production enabled plant optimization, increasing efficiency and eliminating waste. Integrated design and production teams had direct contact with end-users. Being removed from end-use customers often means the upstream processes lack “a uniform understanding of the marketplace and the speed with which the business model was changing” (Michaels, 2010, p. 140). This structure slows process innovation and makes major changes hard to implement—especially with second- and third-tier suppliers—as the flow of innovation is impeded by the lack of understanding of each company’s unique situation. Integrated product teams streamline the transition between development, production, and support. The teams help to lower cost, improve quality, and ultimately create additional value for both producer and customers.

Successful Lean Transformation at Boeing

The superiority of Lean manufacturing over mass production is evident, and the unique environment in aerospace production calls for adaptation to Lean implementation while retaining the same basic principles. Boeing’s Lean transformation started with the 717 narrow-body airliner production line starting in 1999. The company went away from the production method referred to interchangeably as “slant line” or “garage-style” formation in its Long Beach, California final assembly line. The legacy production line shown on the top half of Figure 2 had been in use since 1965 when the first Douglas DC-9 rolled off the production line to be delivered to Delta Air Lines. The “garage-style” production line has the product start in one spot, where it will remain throughout the entire build.
process (Weber, 2001). Having parts and personnel travel throughout the factory rather than staying in one spot significantly increased muda—non-value adding waste (Liker, 2004, p. 43). This age-old “slant line” formation can be traced back to the 1910s when aircraft were first mass-produced for the First World War. In the assembly plant for the 717, up to 20 aircraft in various levels of completeness could be found throughout the plant, and it was impossible to “tell what the health of the line is [since] there is no product movement to act as a pacemaker,” with no way to tell whether customer requirements are being met (Weber, 2001). The new continuously moving 717 final assembly line shown on the bottom half of Figure 2 was designed with Lean in mind. The line travels at 1.6 to 1.8 inches per minute, reducing the number of works in process by 70%, from 20 aircraft to six (Weber, 2001).
The much larger 777 wide-body airliner production line at Everett, Washington underwent a similar Lean transformation in 2006, which ultimately reduced its final assembly process—the time between the arrival of initial fuselage sections to the day the completed jetliner rolls out of the factory doors—from 26 days to 17 days, a 35% time saving (Fetters-Walp & Ferguson, 2010, pp. 28–30). The use of andon—a visual feedback system for indicating production status and a way to stop the production process—is featured throughout the factory (Liker, 2004, pp. 143–144), but the most important transformation at Everett is the creation of a new factory culture. The new culture values the employees, and it increases the program’s competitiveness by making the employees understand how they create value (Fetters-Walp & Ferguson, 2010, p. 30).

Lean Adoption in Aviation Maintenance

The aviation industry is comparable to the aerospace industry as they both face intense global competition and are under significant regulatory oversight, but the different personnel qualifications and service-oriented functions such as maintenance demand a significant deviation from manufacturing-centric Lean implementations.

Lean Adoption by Maintenance, Repair, and Overhaul Organizations

Maintenance, repair, and overhaul (MRO) organizations use Lean techniques to reduce overall maintenance costs, lower aircraft turnaround times, and improve productivity in an age where airplanes are more complex than ever. MRO organizations are primarily responsible for ensuring aircraft can perform their required design functions, and their activities include “the servicing, repair, modification, overhaul, inspection, and determination of the condition of the aircraft especially at scheduled periodic checks” (Ayeni et al., 2016, p. 39). In 2016, Ayeni et al. observed that the proliferation of Lean practices in the MRO industry has its emphasis placed on in-house areas with direct product interaction (p. 48). However, those Lean practices are primarily restricted to the commercial aviation sector and have not reached the military aviation sector. The successes found with commercial MRO organizations can be attributed to their overall quality culture, regulatory requirements, and social awareness. Lean’s development for military aviation is currently limited due to regulation, sclerotic organizational structures, and the lack of operational measures incentivizing transition (Langefeld, 2021).

The emphasis of Lean is placed on tasks such as shop floor optimization, as optimizing the value stream by incorporating the significant unscheduled maintenance demand into the work schedule greatly impacts resource utilization. Unscheduled demands “vary from minor line maintenance input to critical situations where an aircraft due for imminent operation is grounded for immediate hanger or on-wing maintenance support,” necessitating surge capacity and part inventories (Ayeni et al., 2016, p. 47). It greatly increases supply levels held by the organization, and the increased inventory can be considered a Type 1 muda, as they are essential for the end customers even though they are non-value-adding. To combat this, having material and tools arrive at the right location at the right time is critical. Nontraditional environments such as parts warehouses can be improved from their current state by embracing Lean techniques such as heijunka (workload leveling) and visual management (Liker, 2004, pp. 168–169). Langefeld (2021) recommends increasing the frequency of spare parts delivery to at least one per day and to implement an automatic management system for the more expensive equipment. The former will reduce the number of parts held in decentralized material stations rather than in the central store, and the latter can ensure the expensive tools are readily available and secure.

The characteristics that affect Lean in MRO organizations fall under two categories: infrastructural characteristics and structural characteristics, as identified and ranked by 22 aviation industry leaders, professionals, and executives. Infrastructural characteristics are the relational aspects of MRO organizations that focus on the “interaction of the non-physical systems connected by similar value propositions as the production operations” (Ayeni et al., 2016, p. 48). Changes to an organization’s infrastructural characteristics are required to sustain Lean, whereas structural characteristics are factors that are most closely related to implementation. Structural characteristics are the physical resources and technology employed by an organization, and they often have analogies in manufacturing environments, whereas infrastructural characteristics typically do not (Ayeni et al., 2016, p. 45). The key infrastructural and structural characteristics impacting Lean implementation are shown in Figure 3. As a result, Lean initiatives at MRO organizations often focus on facilities and process improvements, with little focus on the nonphysical structures—customer relations, human resources, etc.—required to sustain it. Since MRO organizations are a product of both manufacturing and service activities, merely focusing on half the activities will yield little long-term outcome even though success may seem imminent (Peña Sánchez & Sunmola, 2017, p. 856). Despite the increased use of Lean techniques, the paradigm shift in culture necessary for successful Lean implementation is still lacking at the organization level. The emphasis is placed on labor utilization, production cost savings, and turnaround-time reduction, which are metrics for “transactional” activities.

Product-focused initiatives do not reflect the “relational” aspects required for embracing Lean philosophies and do not reflect the more service-oriented nature of MRO organizations. The production-orientated Lean implementation cannot be sustained as MRO is a product-centric
service environment (Peña Sánchez & Sunmola, 2017, p. 859). It is noted that production and rework costs have not been lowered significantly if Lean initiatives are only conducted on manufacturing activities (Ayeni et al., 2016, p. 49). This approach is taken as many MRO organizations have an operation footprint skewed towards production rather than service-oriented operations.

**Successful Lean Transformation at Lufthansa Technik and FedEx Express**

Success has been documented within larger MRO organizations that are more receptive to change. Lufthansa Technik began its Lean initiatives in 2004, where it began with small projects aimed at improving various parts of the maintenance process. The initial efforts were restricted to physical structures before broadening the scope to improve the entire maintenance process (Brinkman, 2015, p. 6). The company received 110 Kaizen cards from a staff of 150 within 6 months and deemed 85% worth being implemented (Kohrs, 2008, p. 28). The Kaizen cards highlighted existing shortcomings in processes, and process changes allow the company to remain competitive in a growing market. One of Lufthansa Technik’s major sources of revenue is servicing the CFM56 engine, and with the market forecasted to grow from $4 billion to $7 billion between 2006 and 2012. The change to continuous flow production as illustrated in Figure 4 facilitated capacity increase without significant capital investment, making Lean lucrative for companies (Kohrs, 2008, p. 35). FedEx’s aircraft maintenance facility at Los Angeles International Airport underwent a similar transformation in 2009, and the company managed to lower the time required for a C-check from 32,715 to 21,535 man-hours. This Lean implementation reduced the time required to complete a major inspection from 30 to 18 days, which translates to a $2 million saving per inspection (Bartholomew, 2009). The time reduction was achieved without sacrificing quality, with time savings realized primarily through reducing unnecessary time and movement. One pre-Lean bottleneck that was eliminated was at the parts stock room, where mechanics often had to wait for more than 15 minutes to retrieve parts necessary for their work. The stock room was replaced by placing “pallets of special tools and airplane parts right on the hangar floor where the [mechanics] are working,” which allows for easy access and retrieval (Bartholomew, 2009).

Similar trends with Lean adoption can be found in aerospace producers, where the larger producers are more welcoming to change, and smaller firms tend to lag in innovation. This trend can be attributed to their larger capital and human resources available to facilitate Lean adoption and implementation and higher returns on investments from their Lean initiatives. The reasoning behind the slow adoption of Lean in service-orientated activities either can be attributed to a phased implementation plan or could be caused by the lack of a coherent and holistic implementation approach for a product-centric service environment (Ayeni et al., 2016, p. 54). Even though percentage improvements were not available, significant improvements were observed in all production outputs, validating the success of Lean.
Teaching and Learning to be Lean

The education and training that aviation professionals receive differ from engineering education as the emphasis is placed on hands-on experience and practical application. Increased exposure to leading industry practices in manufacturing allows students to be better prepared for more diverse and challenging career fields, and an experimental course on Lean Six Sigma practices was developed for aeronautical engineering technology students at Purdue University’s School of Aviation and Transportation Technology. Introducing Lean in the classroom with course projects allows students to explore ways of operating an advanced manufacturing facility utilizing an operational powerplant laboratory (Davis, 2016, p. viii). A project-based approach allows students to increase their knowledge and problem-solving ability and the course is designed such that it best replicates the industry environment while being in an academic environment. The 28 students enrolled in the Lean Six Sigma Advanced Manufacturing course showed an increase in knowledge level as their scores increased by 8% between the written pre-test and post-test assessments (Davis, 2016, pp. 47–50). The instruction students received in logistics, quality, and manufacturing terms and descriptions will allow them to apply Lean manufacturing and continuous improvement philosophies on future industry assignments.

It is also worth noting that the use of advanced manufacturing methodologies is not well documented in undergraduate programs per the Engineering Technology Accreditation Commission of the Accreditation Board for Engineering and Technology, an indispensable skill for industries in transition. Project management skills go hand in hand with Lean initiatives and are a prerequisite to successfully leading an organization through transformation (Davis, 2016, p. 67). A case study by Kumar et al. (2015) on M/S XYZ, an Indian aviation manufacturer, highlights how academia and industry must connect for an effective Lean transformation as sending a changed person—someone who is familiar with Lean philosophies—back into an unchanged environment will put the individual “into a confused state” (p. 253). This confusion is because the changed people will be uncertain as to whether they should be actively pushing for Lean transformation since the future of the initiative is uncertain. Time is a significant constraint as the long-term vision required for Lean success can be incompatible with managerial pressure from deadlines and their vision for improvements (Hill et al., 2017, p. 33). For example, the limited duration of an academic term is a limiting factor for the project’s depth in Davis’ work. Lean adoption in the aviation industry requires collaboration between all stakeholders: production, service, customers, and education. The unique service-oriented nature of the industry is different from those in manufacturing enterprises, but the success of Lean is evident from the reduced turnaround time, increased knowledge level, and lowered cost.

Similarities and Differences of the Industries

The aerospace production and aviation maintenance industries are focused on different stages of an aircraft’s life. There are numerous similarities and differences between the two industries that may affect Lean adoption and looking at their industry characteristics may offer some insight. When compared with the number of automobiles in
use, the numbers of aircraft in service are minuscule. In the United States, there were 286.9 million vehicles registered in 2020 (US Vehicle Registration Statistics, 2021), a number far greater than the 288,000 registered civil aircraft in the same year (Aircraft Registration, 2021). The significantly smaller aircraft production and maintenance markets make it difficult to create the economy of scale often found in traditional Lean implementations. The safety requirements of customers in both markets call for higher production quality and better maintenance oversight. The advanced materials used in aircraft construction, higher complexity compared with other products, and the potentially catastrophic consequences of errors all place additional demand on the producer and maintainer. Processes must be reliable, be fully reproducible, and be able to maintain tight tolerances, with these factors all culminating in the high safety standards and safety record of air travel (Materials Research Agenda, 1993, pp. 14–15).

**Similarities: Organization Size and Training**

The significant overlaps in industry characteristics between aerospace production and aviation maintenance can be leveraged for a unified Lean implementation strategy. In both industries, the knowledge and integration of Lean for smaller organizations are noticeably lower than those of their larger peers. Barriers for SMEs to transition towards Lean include the “lack of definition of the customer, the rigidity of the organization, and the lack of incentive to improve customer satisfaction for the case of monopolies” (Alefari et al., 2020, p. 230). Additionally, as their desire for Lean is profit-focused, little emphasis is placed on changing organizational culture. The potential benefits of engaging with employees, customers, and suppliers are lost and it makes their Lean transition less durable (Alefari et al., 2020, p. 235). The durability problem can be remedied through employee involvement, effective leadership, and management support (Alkhoraiﬁ et al., 2019, p. 11). One of the cornerstones of Lean is “add[ing] value to the organization by developing your people and partners,” and this is particularly important in the aerospace and aviation industries due to their highly specialized education and training requirements (Liker, 2004, p. 184).

While there is a different focus in their educational outcome, with aerospace education aimed at theoretical understanding and aviation education emphasizing practical applications, both groups benefit greatly from understanding Lean as a framework rather than specific tactics for increasing revenue. The most successful companies actively train their employees to recognize, act, and eliminate waste. Companies also need to provide people with a common language when talking about processes, which can be achieved by training people in Lean at different levels (Gingerich, 2011, pp. 2–4). The common language facilitates effective communication across different functional areas and can lead to better performance. At Boeing, all stakeholders in the design process—not just product designers and engineers, but also those from logistics, operations, marketing, research and development, and manufacturing—are familiar with Lean and this helps avoid creating baked-in operational problems. This high level of familiarity is accomplished through Lean training, Lean workshops, and providing a Lean toolkit to all employees, and it is used to improve productivity on what they are already doing (Grace et al., 2017, p. 8). Airbus also implemented a similar program under the “Lean Learning Academy” banner, and the training provider Ingenics has developed standardized training measures that can be evaluated and certified. The training program delivers practical knowledge and facilitates the sharing of technical expertise, and it is anticipated that Airbus can “[reduce] development times and costs by 20 to 30 percent” through adopting Lean thinking (Lean Learning Academy, 2020).

**Differences: Demand and Operation Orientation**

Despite the similarities in industry characteristics, there are still some differences between Lean implementation in aerospace production and aviation maintenance. Production schedules for aircraft are often planned years in advance due to the strong order book of aircraft manufacturers, and production slowdowns are mostly caused by global economic conditions (Cooper et al., 2021, pp. 29–36). While major inspections for aircraft are often scheduled months if not years in advance, not all maintenance tasks can be predicted. This is due to the demand for unexpected major repairs when an aircraft is damaged or grounded for mechanical reasons. The lack of parts at the MRO station can easily turn an hour-long fix into a multi-day affair that costs upwards of $200,000 for a transatlantic widebody airliner flight. Most of the cost for aircraft-on-ground events (AOGs) is manifested in lodging for passengers, the need to reschedule crew, lost future business, and the cascading effect on the return flight (“Aircraft on Ground,” 2017). The obvious way to avoid situations like this is to stock warehouses full of parts such that they never run out, but this is impractical and comes with an exorbitant price tag. Most airlines optimize their value stream with a three-step approach to “estimate the costs of AOGs; model the part stocks needed to minimize them; and then buy, lease or arrange access for desired levels of stocks” (Canaday, 2016). This value stream is in contrast with a typical manufacturing-centric Lean implementation, which considers inventory as a form of *muda* and thus should be eliminated whenever possible. It is significantly easier for aerospace manufacturers to predict their demand when compared with MRO organizations as there is little surprise to their demand. Unexpected repairs conducted by MRO
organizations necessitate additional inventory and staff be available at a moment’s notice, but routine maintenance tasks can be optimized following Lean principles much like any other organization.

Aviation maintenance organizations also have a significantly larger customer-facing component than aerospace manufacturers. The high variability of work performed at MRO organizations and the significant demand from external customers call for a Lean system that supports a customer-driven business model. The business model encompasses “production planning and control, process management, quality, scheduling, material management, and production,” and is supported by a robust organizational system (Lean MRO, 2010, p. 5). The traditional focus for Lean is to improve internal operating efficiency through optimizing a company’s value stream. MRO organizations must also satisfy the end customers’ demands, and that can be achieved by paying attention to customer relations and measuring value from the perspective of the customer rather than the company (“Four Principles,” 2021). Despite the importance of customer communication, it is not consistent across the nine maintenance organizations surveyed by Sunjka and Murphy (2014). The origin of communication varied from senior management to the marketing department, and only one-third of the organizations surveyed contacted their customers more than once a month. Only two of the nine MRO organizations surveyed had a formal method of determining customer needs, and only five of them tracked customer satisfaction (Sunjka & Murphy, 2014, p. 71). Without appropriate lines of communication, the dramatic reduction in defect, cost, and inventory cannot be realized (Mathaisel, 2005, p. 631). Correspondence should be delivered in an effective and timely manner such that the information can ultimately enhance the customers’ decision-making abilities. A Lean practitioner must be cognizant of the different needs of the aerospace production and aviation maintenance industries such that they can implement an organization-specific, sustainable, and achievable transformation.

Conclusion

Lean philosophy has been adopted in many industries to reduce costs and increase productivity. Despite the unique challenges posed against Lean adoption in the aerospace industry, such as lower production volume and higher complexity, there are success stories across the globe, especially with larger producers. Similarly, large aviation MRO organizations are more inclined to adopt Lean, but the industry also faces hurdles, including unscheduled maintenance demands and its service-oriented nature. Smaller producers and MRO organizations tend to struggle with Lean adoption, as the flow of information between them and end-use customers is not as direct. Smaller firms must strive to overcome the information disconnect either by gathering feedback from end-users directly or having information relayed to them via first-tier suppliers with end-user interaction. Those who fail to or refuse to embrace Lean face a risk of becoming obsolete themselves as they will be less efficient and less prepared for an increasingly competitive market.

The different operational characteristics between aerospace producers and aviation maintenance organizations call for different focuses in their pursuit of Lean. Moving an aerospace producer from mass production to Lean is comparable to Lean transition in other industries, albeit with lower production volumes and substantially higher complexity. The transition will still be focused on reducing inventory, creating flow, and lowering the time between order and delivery. However, MRO organizations also have a major customer-facing component since they are operating in a product-centric service environment. That calls for deviations from production-centric Lean practices, as infrastructural concerns such as customer relationships and human resources play a significantly larger role and are critical to sustaining Lean initiatives. Success stories from Boeing, Lufthansa Technik, and FedEx Express all showcase the potentials for adopting Lean despite the challenges it might pose at the beginning.

Successful Lean adoption requires effective project management skills, together with follow-through and continual support from management. The largest barrier to success is often culture, rather than industry-specific factors, and changing culture requires time, effort, and the willingness to let the people closest to the product take the lead. Through surveying published works on Lean implementation in product development, production, supply chain, maintenance, and education, it is shown that flexibility with Lean principles and continuous improvement is the key to success.

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Author Bio

The author is a graduate student in engineering management and a recent mechanical engineering graduate of Purdue University with experience as a corporate consultant, engineering intern, teaching assistant, and aviator. His academic focus includes human factors and manufacturing systems, and his research draws from both historical perspectives and modern contexts.

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