APPLYING LEAN IN AEROSPACE MANUFACTURING FOR WASTE REDUCTION

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Abstract: Lean manufacturing shows significant promise for addressing various simultaneous, competitive demands, including high process and merchandise quality, low cost, and reductions in lead times. These requirements have been found within the aerospace sector, and efforts are now well established to implement lean practices. Although lean manufacturing was originally developed for the automotive industry, aerospace manufacturing industries have found that these lean principles can also be applied in this high-precision industry to improve production efficiency significantly. In this paper, the main objective is to provide background on lean manufacturing, present a summary of potential wastes and introduce the tools and techniques that are used to transform the industry into a high-performing lean enterprise. The method applied in this article is divided into three major parts. Firstly, define lean manufacturing and lean cycle for the aerospace sector. Secondly, examine lean implementation in the aerospace manufacturing sector. Finally, discuss the lean action plan in the aerospace sector. The goal of lean implementation in the aerospace sector is to construct a learning organization and achieve continuous improvement. Thus, the aerospace manufacturing suppliers can increase their competence within the present competitive market.

1. INTRODUCTION

Initially, the word "lean" was popularized by the book the machine that changed the planet (Womack, et al., 1990). This word crystallized a broad range of practices and principles where continuous improvement was made possible through the systematic elimination of waste, the reduction of in-process inventory, the utilization of just-in-time delivery, in-station process control, continuous improvement suggestions, systems thinking, and other related elements (Krafcik, 1998; Womack and Jones, 1996). Lean practices and principles encompass longstanding quality principles (Deming, 1987; Juran, 1998) and newer developments, like Six Sigma (George, 2001).

Lean manufacturing is an approach to help factory to identify and eliminate production waste, improve product quality, and reduce production cost (Salunke and Hebbar, 2014). There are at least seven (07) types of production wastes which are shown in table 1.

Table 1. Production Wastes and Causes

Types of waste	Causes
Waste of overproduction	On some occasions, some finished products could not make their way to the customer. Those products are called a waste of overproduction. This waste occurs due to an earlier production timeline or a higher production than customer needs.
Waste of motion	The movement of employees in working on products is unavoidable. However, if there is a movement that does not provide added value to the product, it is

	categorized as waste. Those movements include searching, selecting, or stacking components, tools, and so on.
Transportation waste	In a well-designed system, workplaces and storage areas are close together so that material transfer is nearby. The equipment is placed where it is used, and material is transferred to the process quickly.
Processing waste	In some cases, changes in product design often cause a reduction in some parts of the final product. Waste of processing occurs due to unnecessary processes or carry out inefficient processing.
Waste time	This type of waste can be divided into two categories, namely waiting time and queuing time. Waiting time occurs when a part has finished, but other parts that will be assembled with it have not yet completed. Queuing time occurs when a part has finished but cannot continue because the next machine is still doing another job.
Defective product	This waste arises from producing defective products or components or requires repair. Repairing or reworking, scraping, producing replacement goods, and inspections means that additional handling, time, and effort are needed.
Unnecessary Inventory	This waste arises from excessive inventory. Expenditures due to waste include warehouse costs, costs due to obsolete products, and damaged products.

The lean cycle (Plan-Do-Check-Action (PDCA)) cycle is shown in figure 1.

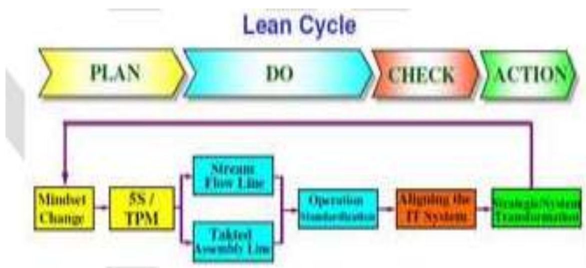

Figure 1. Lean Production Cycle (Bharadwaj, et al., 2015)

The aerospace industry allows a valuable place to examine lean implementation. It is a diverse sector of the economy surrounding airframes, engines, space and missiles, avionics, and a vast array of second and third-tier suppliers. There are huge competitive challenges in both the civilian and military parts of this industry, driven by the end of the Cold War, the rise of global competition, the development of new materials and new innovative technologies, and the emergence of what are termed "dominant designs" in many segments of the market (Utterback, 1996). In this mix, lean manufacturing practices and principles have been highlighted as central to the revitalization of the industry. For example, Norman Augustine, retired Chairman and CEO of Lockheed Martin, called for the application of lean principles from the machine that changed the world (Womack, et al., 1990) to this industry and commented that "The U.S. aerospace industry has restructured what it is now, it must restructure what it does and how it does it" (Murman et al., 2002).

In the 1990s, the aerospace company was trying to implement a lean manufacturing approach to production using Kawasaki Production System. Boeing, a renowned aerospace company, applied the lean manufacturing concept in 1997 and successfully constructed a moving assembly line in 1999 at Long Beach Plant by building 100-seat 717 aircraft. Boeing 747 final assembly line applied lean manufacturing technology in 2001. The results showed highly optimized production flows and processes, reducing cost and flow time from the traditionally 24 days to the targeted reduced 18 days (Koskela, 1992).

2. LITERATURE REVIEW

Lean aircraft designers think that a new 'right first-time' culture in aerospace manufacturing will do for aircraft what it did for the car industry a decade ago. Nowadays, panels and components damaged in operation can be quickly replaced at the front line without special customization in the same way that car parts are ordered up and fitted in the commercial world from a long time ago. Employees involved in Eurofighter production from the design to the logistic support are grouped in integrated production teams (IPTs). Each IPT is now responsible for its budget and accountable for its section of the aircraft (Cook, 1999).

The adoption of lean practices is evident in the USA and the U.K. aerospace sectors. In the USA, Lockheed Martin's Aeronautics Sector declared 1999 as the 'year of lean implementation and then rigorously applied lean techniques to the F-16 and F-22 fighter programs and the C-130J military transport aircraft. In the U.K., BAE Systems military aircraft plants had been heavily involved in implementing lean practices within their businesses from a long time ago. The Samlesbury site became the company's flagship manufacturing site, believing that lean manufacturing was central to controlling costs on the Eurofighter program. However, BAE Systems thought that the aerospace industry was 10-15 years behind the automotive sector in implementing lean activities (Flight International, 1998).

Lean ideas are now being transferred throughout the U.K. aerospace industry. Significant initiatives are also ongoing in many aerospace manufacturing firms, including Airbus U.K., Rolls-Royce plc, Smiths Aerospace, TRW Aeronautical Systems, etc. Lean improvement efforts are also being patronized in both the USA and U.K. by national research programs for example, the U.S. Lean Aerospace Initiative at Massachusetts Institute of Technology (MIT) and the U.K. Lean Aerospace Initiative, a consortium consists of the Universities of Warwick, Bath, Nottingham, and Cranfield.

Three factors have caused lean to become an issue within the aerospace sector. First, the end of the Cold War evoked drastic reductions in defense procurement budgets resulting in reduced military markets. The defense industry could no longer justify the cost-plus mentality that characterized the Cold War era and faced the challenge of seeking new markets (Aviation Week and Space Technology, 1992; Interavia, 1999). Second, passenger demand felled suddenly following the Gulf War, which forced airlines to cancel or postpone civil aircraft orders. This followed a time when civil aircraft orders increased at unprecedented higher levels. The inability of the industry to respond to unexpected changes in demand was reflected by long lead times (Aviation Week and Space Technology, 1999). Third, now with other sectors, globalization has become a central issue. The rise of globalization has necessitated a complete rethinking for some industries regarding how they can organize and reconfigure themselves to cope with it. These factors signaled radical changes for the global aerospace industry. There was now over-capacity in the market, and profits were declining (Cosentino, 1999). As a result of these factors, several significant players within aerospace are pursuing lean practices. For example, Boeing, a renowned aerospace company, was facing up to some of these challenges as it implemented urgent operational improvement strategies to:

1. Achieve more excellent quality on the first pass throughout Boeing-the goal is 90% improvement in manufacturing quality.
2. Organize corporate-wide work teams that are fully accountable for their work products, and all have the metrics they need to measure their performance.
3. Create a culture that encourages employees to propose better ways to meet performance goals.
4. Move up the value chain, i.e., focus on core competencies.
5. Reduce the company's cost structure substantially.
6. Globalize to a greater degree (Aviation Week and Space Technology, 2000).

However, the applicability of lean practices to sectors other than automotive had been questioned (James-Moore & Gibbon, 1997). Lean had its roots within the automotive industry, and the contrast between this high volume setting and the low volume environment of the aerospace industry was enormous. Jina et al. (1997) provided insights into some of the sector differences between automotive and aerospace companies. However, they did not mention how this impacted the manufacturing transformation process, and this was where the literature on manufacturing strategy became important. From a manufacturing point of view, Hayes and Wheelwright (1984) and Hill (1995) provided templates that showed profound differences between high volume (line production) processes, common to automobiles, and low volume (project-based) processes that pervaded aerospace. Hill (1995) pointed out that the differences between these two manufacturing environments extended beyond production transformation characteristics to competing priorities. To use the Hill (1995) terminology, there were significant differences between order-winning and order-qualifying criteria when contrasting high and low volume settings. The transfer of practices across different sectors could present difficulties. These sector-specific requirements could not be ignored and glossed over in the pursuit of a particular paradigm. However, differences such as volume levels should not necessarily present an obstacle to the implementation of lean in aerospace because numerous successful examples of the application of lean have been drawn from a variety of industrial sectors (Womack and Jones, 1996; Henderson and Largo 1999; Jenson et al., 1996). Womack and Jones (1996) prescribed a detailed account of the introduction of lean principles within Pratt & Whitney, one of the world's leading aero-engine manufacturers. Moreover, the aerospace sector might have advantages over automotive in terms of applying lean principles. The lower volumes mean that the aerospace sector (at prime and upper-tier levels mainly) was closer to the lean ideal of single-piece flow than the automotive sector. Another possible concern was that aerospace was ten years behind the automotive industry about implementing lean practices. Although this might provide learning opportunities, the time lag was an important issue. However, we should also keep in mind that the transfer of lean practices had not been fully disseminated even within the automobile industry, although the initial efforts began some ten years ago before the aerospace sector. For example, Kochan et al. (1999) showed that although lean production systems seemed to be diffusing throughout the world, there was much variation across countries and firms and firms. In addition, the automotive sector might be accused of shop floor myopia, having concentrated on creating lean final assembly plants and supply chains over the past ten years. The automotive industry was only now coming to grips with applying lean in the extended enterprise (Womack and Jones 1996) by looking at ways to reduce waste throughout the distribution process and provided the final customer with their exact requirements. This had become evident in the '3-Day Car' ambition within the industry (Holweg and Pil, 2001]. However, rather than 'catching up with such developments in the automotive sector, the aerospace sector already 'builds to order', only producing aircraft that their commercial and military customers required. The aerospace sector adopted lean practices with a "Lean Enterprise" mindset, particularly as 80% of the cost was built-in at the design stage. Therefore, the concern over the perceived ten-year gap might not be as much of a disadvantage as it first appeared. While the aerospace sector might have some benefits in implementing lean, the challenges of lean implementation were real and proved difficult for many other firms. As Karlsson and Ahlstrom (1996) pointed out, traditional ways of thinking and practices were difficult to shed, and we could thus expect such a radical change to be fraught with difficulties.

V. Crute et al. (2003) discussed the critical drivers for lean in the aerospace manufacturing industry. They informed that implementing lean within aerospace was not necessarily more complicated than implementing lean within high-volume sectors, automobiles. The challenges were different but not more difficult. They offered critical conclusions from their findings and tentative lessons for other companies. First, lean capabilities were not merely firm-specific but were, instead, plant-specific. There were differences in the rate of progress made and differences in the procedure taken to lean implementation. Second, it could not be assumed that the characteristics of the 'best performing' site within a firm that had multiple plants would, necessarily, be transferred to other plants within the same company. Techniques, including benchmarking between sites, might help but needed to be 'Lean Champions' between sites if lean practices were to be disseminated among plants within the same firm. Third, for lean to be implemented, plant-specific manufacturing strategies must be in place that was comprehensive and holistic in scope and content. Results might also be achieved more readily when improvement activities focused on all or a large part of an identified 'product value stream' rather than on a functional area that produces a range of products. Similarly, faster results seemed possible when established process ownership was rather than several products sharing production processes. Four, operations managers had to be willing to take on a more strategic role than had been the case in past manufacturing paradigms. This was a problematic issue because lean production had emerged from the profound changes of manufacturing processes over time. However, as Brown (2000) found that the transition from craft through mass production to the current era of lean often resulted in operations management being absent from the most senior levels of the firm as enterprises became larger and more organized around functions and although there had been increasing importance placed on operations personnel in terms of their contribution to the firm's capabilities, including lean production (Womack, et al., 1990; Kenney and Florida, 1993). Their findings indicated the need for operations managers to have a strategic and not merely tactical role if lean implementation was to be successful. Senior management had an important role to play in presenting a coherent vision for their business, clearly communicating business strategy, and indicating how the lean philosophy and practices fitted with the needs of the business. There also needed to be an awareness of the impact of the consistency of senior management messages. Questions needed to be asked concerning whether the philosophies and initiatives being promoted were consistent, timely, and necessary. Five, their findings indicated that lean implementation could be achieved more rapidly in plants where the culture supported autonomous working and learning through experimentation. Where such a culture did not exist, senior managers should play a key role in creating a context where change was possible. This required leadership and a consistent message of support. Six, aspects of improving performance, such as changing factory layout, required time, and physical space, were available if significant results were to be achieved.

3. RESULTS AND DISCUSSION

It was found that most wastes occurred in aerospace manufacturing activities. Zahra et al. (2020) performed a study for the performance improvement in aerospace manufacturing through lean. They found that waste of motion was the highest among other waste with a score of 44, followed by waiting with a score of 24. The third highest waste was excess processing with a score of 2. The causes of these wastes were lack of facilities such as machines and tools and inefficient operators in picking and mixing sealant. The method that they applied was divided into three major phases. Firstly, they evaluated the current system performance using Value Stream Mapping (VSM). Secondly, they determined the dominant waste by cooperating waste finding checklist. Finally, they developed a lean action plan.

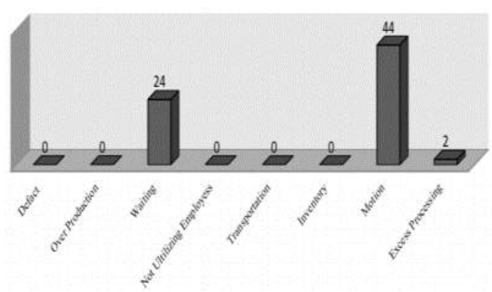

Figure 2. Waste in Aerospace Production (Zahra et al. 2020)

The overall processes led to 2 days and 12 hours of waiting time. In respect to that time, the next step was to group the activities into Value Added (V.A.), Non-Value Added (NVA), and Necessary Nonvalue Added (NNVA). Hence, the cause of waiting times could be identified. The results were as follows; Value Added was 44,520 hours; Non-Value Added was 418 hours, and Necessary Non-Value Added was 49,520 hours. Waste Finding Checklist (WFC) was used to find the wastes in the elevator production. A series of discussions with experts were performed to fill the WFC filled. From the WFC the waste of motion had the highest value of 44, then waste of waiting was in second place with 24. The complete result is shown in Figure 3.

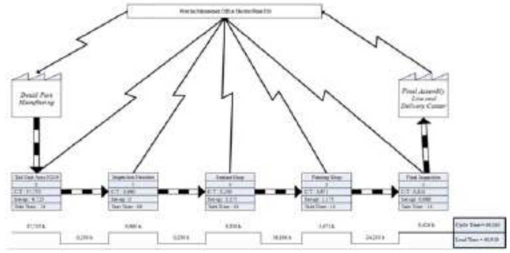

Figure 3. Current Value Stream Mapping (Zahra et al. 2020)

After all types of wastes were identified, Fishbone Diagram was applied to determine the root cause of the problem. The waste motion caused by 18 production process activities caused by lots of unnecessary movements or excess movement could cause additional time in the production process. Improvement analysis focused on waste of motion in several production process activities. The result was a program to change the layout to make the JIG elevator closer. Another program was to add sealant space to the elevator production process location so that the operator did not have to bring the sealant too far from the elevator production process room. The last program was to restrict the operators from taking and mix sealant. In addition, the labeling of the machine or tools was done to facilitate the operator is working. Based on those improvements' program, it reduced cycle time and lead time. Future Value Stream Mapping by those programs is shown in figure 4.

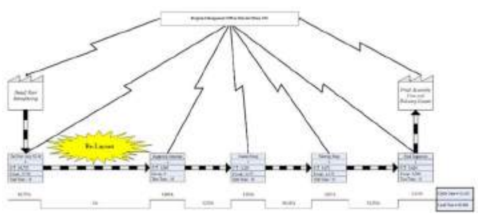

Figure 4. Future Value Stream Mapping (Zahra et al. 2020)

V. Crute et al. (2003) performed a case study to implement lean in the aerospace manufacturing industry. They implemented lean in two sides (Side A and B). They found that despite the similarities, the timescales for progress differed considerably, with both sites having achieved significant results. At Site A, lean changes were implemented and got output within six months. By contrast, at Site B lean changes were still being kept in place after 18 months of effort. Site A has enjoyed a significant increase in orders for spare components requiring the site to double its previous output approximately. Senior managers in the company found that existing resources, equipment, and systems would not be sufficient to meet future demands and, therefore, a change strategy had to be implemented. It was decided that lean techniques would be piloted in one department, which was underperforming, and that the plan would be that lean practices would then apply from here to the whole site over time. Improvement targets were precise and linked to lean indicators, including lead-time reduction, increased stock turns, and the introduction of pull systems. The department was performed in machining, sub-assembly, assembly, and testing processes. Substantial results were achieved within six months, as shown in Table 2.

Table 2. Lean performance improvements at Site A (Crute et. al., 2003)

Site A	Starting point (Time = 0)	Target (0 plus 6 months)	Achieved (0 plus 6 months)
Lead time	8 weeks	4 weeks	5 weeks
Stock turns	2.3	10	5.3
Production capacity per month	450	800	800
Pull systems	None	In place	Sub-assembly

Single piece flow	40/50-part batches	Reduce batch size	5-part batches
Scrap and rework	£3,500 per week	Reduce	£750 per week

At Site B, the drive to implement lean practices was motivated by recognized success at Site A and more modest demands for a 20% increase in production. The area identified for lean improvements involved assembly processes only with machining and testing in other parts of the organization. Improvement goals included the increasing output of 'delivery kits' and improving labor efficiency. Other targets for improvement were more generic, including using a range of management quotes from interviews- 'establishing customer-focused areas' and 'establishing continuous improvement practices within site. Few performance measures were at hand within the target area to start the improvement efforts, although metrics were available for the whole assembly section of which the target area formed one part. No plans were made to set formal targets and measure the achievement of the more generic goals. Production and productivity targets were achieved, and some progress was achieved in establishing customer-focused areas. While continuous improvement practices were accepted within the area, there were some reservations concerning the degree to which such practices had become embedded and would be sustained. An overview of Site B is provided in Table 3.

Table 3. Lean performance improvements at Site B (Crute et al., 2003)

Site B	Starting point (Time = 0)	Target	Achieved (0 plus 18 months)
Delivery kit production capacity	100 units	20% increase	120 units
Labor efficiency	Actual Data not released	20% improvement	20% improvement reported
Establish customer focused areas	No formal measurement in place	No formal targets or measures set	Estimated 15% of target areas established
Establish continuous improvement practices	No formal measurement in place	No formal targets or measures set	Continuous improvement practices adopted

Table 4. Summary of the critical factors influencing the rate of Lean improvements (Crute et al., 2003)

	Site A	Site B
Rate of Lean implementation	Significant effects within six months	Significant results following 18 months of implementation efforts
Change strategy	1. Holistic approach 2. Specific Lean targets 3. Performance measures developed at the outset of implementation. 4. Formal Lean training provided	1. ‘Piecemeal’ approach 2. Generic targets 3. Performance measures developed at later stage in implementation. 4. Informal dissemination of lean concepts.
Site culture	1. Satellite site 2. Autonomy/willingness to experiment	1. Central site 2. High visibility/ blame culture 3. Bureaucratic
Product focus	1. Changes targeted on ‘product value stream. 2. Processes mainly dedicated to the Product family. 3. Greater process ownership 4. Limited dependency on other areas	1. Changes targeted on a functional area (assembly) 2. Processes shared by several products. 3. Less process ownership 4. Highly dependent on other areas
Senior management commitment and consistency	1. High degree of support 2. Consistent messages	1. Conflicting management 2. Initiatives/people management philosophies 3. Changes to Lean champion’s responsibilities

Time and space for performance improvement	1. Increases in customer orders 2. created a pull for change. 3. Creation of additional time and space for changes	1. Drowning in orders 2. Limited time and space available for changes

4. CONCLUSION

This study defines the lean concepts, summarizes the lean cycle for lean implementation and practice, and develops the lean production Implement model to strengthen the aerospace market competitiveness. The lean concept can apply within the manufacturing process of the aerospace industry and the business process. Especially for aerospace manufacturing suppliers, they need to scale back their cost to extend their competitiveness. The concept of lean production is a continuous improvement process. It is a long-term journey and effort. The lean Implement model incorporates four categories, i.e., human resources, machine, method, and function. The scope/level of lean topics and environment will become wider/higher than before in the aerospace industry through the continual lean cycle. The goal of lean implementation is to strengthen the management performance of an enterprise. Through the top management commitment and companywide involvement, the resources can be aligned and focused to implement lean activities. The goal of lean implementation in the aerospace industry is to construct a learning organization and achieve continuous improvement. Thus, the aerospace manufacturing suppliers can increase their competence within the present competitive market.

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