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State-of-the-art of 'Lean' in the Aviation Maintenance Repair Overhaul Industry

P. Ayeni[1, 2,*], T. Baines[2], H. Lightfoot[2], P. Ball[2]
[1]*Hawker Pacific Aerospace, Hayes, UB3 1HP, UK*
[2]*Department of Manufacturing, Cranfield University, Cranfield, UK*

Abstract:

The increasing need for Maintenance Repair Overhaul organisations (MROs) to meet customers' demands in quality and reduced lead times is key to its survival within the Aviation industry. Furthermore, with the unpredictability in the global market and difficulties with forecasting characteristic of the MRO industry there is an increased need for the re-evaluation of the operation models of organisations within this sector. However, severe economic turmoil and ever increasing global competition introduces the opportunity for the adoption of a resilient, tried and tested business operation model such as 'Lean'. In order to fully understand this concept, its long-term viability and its application within the aerospace MRO sector, this paper presents the state-of-the-art in terms of the adoption of Lean within the MRO industry by carrying out a systematic review of literature. This paper establishes the common perception of Lean by the MRO industry and the measurable progress that has been made on the subject. Some issues and challenges are also highlighted including the misconceptions that arise from the direct transference of the perception of Lean from other industrial sectors into the aerospace MRO industry. Also discussed are the 'enablers and inhibitors' of Lean within the aviation industry. This paper exposes the scarcity on literature and the general lagging behind of the industry to the adoption of the Lean paradigm and thus highlights areas where further research is required.

Keywords: Lean, Maintenance Repair Overhaul, Service, Outsourcing.

NOTATIONS

MRO	Maintenance Repair Overhaul
OEM	Original Equipment Manufacturer
BAMP	Bundled Asset Management Programme
ICS	Integrated Customer Support
HPA	Hawker Pacific Aerospace
TAT	Turn Around Time
LCC	Low Cost Carrier

1. Introduction

Competition within the aviation industry is fierce [1]. Since 1992, the United States has signed more than 50 bilateral Open Skies Agreements (OSAs) with the main objective of promoting an international aviation system based on competition among airlines with minimum Government regulation. The Government's motivation to support these OSAs is the desire to facilitate the expansion of air-transport opportunities, making it possible for airlines to offer the travelling and shipping public a variety of service options at the lowest prices [2]. The positive effect of this agreement is not only reflected in the passenger population rise and financial gains but this liberation also lends towards increased international competition within the aviation sector. However, fluctuations in the global market resulting in difficulties with forecasting and an increased pressure for reduced inventories, is placing a critical focus across all industrial arms of the aviation industry (military and civil). Significant proportions of this pressure is been cascaded into its service arms – Maintenance Repair and Overhaul (MRO) sector [3]. With fewer airline startups and increased exposure to global competition, the competition is fierce.

In dealing with these pressures, new strides in the application of Lean manufacturing principles are achieving surprising new gains and innovative solutions for MROs [4]. Literature review shows that there seems to be a strong emphasis on adopting Lean techniques within manufacturing operations [5]. Kilpatrick [6] explained that Lean manufacturing facilities increased capacity, quality, and productivity while simultaneously reducing inventory and order lead time(s). Indeed, there is little doubt that the correct application of Lean principles in the service sector represents an opportunity for improvements in competitiveness [7]. This paper aims to provide an insight into the state-of-the-art of Lean within the aviation MRO industry.

Consistent with literature review methods, the initial approach to the study contained in this paper involved the identification of relevant databases prior to any search that was carried out. These search operations first employed the use of an array and combination of keywords and phrases closely associated with the research subject (e.g. Lean, aviation, maintenance, MRO). The results were then reviewed and the shortlisted publications were then critically assessed and evaluated to present a set of key findings based on their consistency in literature. Conversely, some key issues were also raised in areas where the results from literature review were inconclusive or contradicting. By establishing these findings and issues, this paper provides a state-of-the-art review of Lean within the aviation MRO industry and thus provides a platform for more detailed research to improve the understanding of Lean thinking within the aviation industrial sector.

This paper is structured as follows: First, the industrial context and the scope of this study are further explained. Then the research methods including the selection process for the material upon which this study is based on is explained. The paper then presents the analysis of the literature in the form of key findings. Finally, the results of this analysis are discussed and summarised with some conclusions drawn.

2. The Aviation MRO Industry: Industrial Context

To be able to establish the application of Lean in an industrial context within the aviation MRO industry some questions naturally come to mind: 'What is an MRO'? What are the characteristics or the functions of an MRO? Are there any classifications or groups within the MRO industry? What challenge(s) does the MRO industry face? Seeking answers to these questions will help to set the stage upon which the state-of-the-art of Lean can be established.

2.1. Illustration of a *Typical* 'Maintenance Repair Overhaul' Organisation

Aircraft maintenance checks are carried out periodically after specified time or usage. These checks are categorised into A, B, C, and D checks with the light checks referred to as *A and B* checks and the heavy maintenance checks regarded as *C and D* checks. The aviation MRO industry is primarily responsible for the retaining or restoring of aircraft parts in or to a state in which they can perform their required design function(s). This includes the combination of all technical and corresponding administrative, managerial, supervisory and oversight activities. Inclusive of the described periodic checks, MRO-type activities are principally the servicing, repair, modification, overhaul, inspection and determination of condition of the aircraft [8]. The main role of the aviation MRO sector can thus be summarised as the arm of the aviation industry that is essentially responsible for the provision of a fully serviceable aircraft when required by the operator at affordable and reasonable cost with optimum quality. An example of a typical MRO organisation is 'Hawker Pacific Aerospace' (HPA). With two facilities in the UK and America, HPA specialises in the repair and overhaul of Landing Gears (aircraft/helicopters), Hydro-mechanical components, Wheels, Brakes and Braking systems, Flap Tracks and Carriages, Flight Controls, Constant Speed Drives, Integrated Drive Generators and even the distribution and sales of new and overhauled aerospace spares.

2.2. Classification of MRO Organisations

Organisations within the aviation MRO industry can be classified using various criteria. For the purpose of this study, MRO organisations will be classified based on the nature or type of the function they perform and on their organisational structure. However, there is a growing new trend of OEMs offering MRO-*type* services which will also be briefly discussed.

2.2.1. Classification of the MRO industry based on 'type-function'

The MRO-type functions can be broadly classified into the following: Heavy Maintenance Overhaul/Major Modifications; Engine Overhaul; Retro-fits and Conversion; Component Overhaul; Line Maintenance and Avionics. Due to the nature and type of overhaul required, MRO firms are usually *specialised* and *specific* in the type of overhaul they perform. The specialist roles by which MRO organisations can be classified are briefly described below and are illustrated in Table 1.

- Heavy Maintenance Visit: This usually involves the disassembly of major components of the aircraft for detailed inspection and repairs.
- Engine Overhaul: This ranges from routine service checks to the complete repair of the engines. It is potentially the largest sector within this industry.
- Component Overhaul: This usually involves the overhaul of all other parts not categorised under the heavy maintenance category. These range from Landing Gear to Fuselage overhauls.
- Line Maintenance: This function involves the routine maintenance of the aircraft. MRO organisations within this category are responsible for the frequent inspection of the aircraft to ensure its safe in-service use. MRO organisations within this category can also carry out minor repairs as advised/required by OEM periodic publications [9].
- Avionics: MRO organisations in this category specialise mainly in the overhaul of the aircraft avionics and associated components. Avionics are typically the various electronic components and systems developed under various types of disciplines (both military and commercial) into a cohesive working master system that would increase the overall efficiency of the aircraft.
- Retro-fits and Conversions: This sector is responsible for the major and minor design retro-fits and the conversion of passenger aircrafts to freighter aircrafts.

Although all of the described functions are different in operation, there are huge similarities (in principle) in the manner in which these services and operations are carried out. However, an understanding of the different types of MRO organisation will facilitate a better understanding in the adoption of Lean within the MRO industry.

Sector	Examples
Heavy Maintenance Visits	AAR Corporation (Global, HQ Illinois, USA); SR Technics (Global HQ Switzerland, Zurich); ST Aerospace (Global, HQ Singapore); GE (HQ US)
Engine Overhaul	Lufthansa Technique (Hamburg, Germany); Rolls Royce (HQ UK).
Component Overhaul	Hawker Pacific Aerospace (UK/USA); APPH (UK); Ameco (China)
Line Maintenance	Scandinavian Aircraft Maintenance (Norway); SIA Engineering (Singapore)
Avionics	Honeywell (Global); Selex Galileo Global (Italy/UK)
Major Modification/Retro-fits/ Conversion	Aeronautical Engineers (USA); Airbus (Dresden, Germany), Haeco (Honk Kong, China)

Table 1: MRO-type Functions and Logistics

2.2.2. Classification of the MRO Industry based on Organisational Structure

Using the organisational structure as the criteria for classification, MRO organisations can be broadly grouped into two – *independent*/*third-party* MRO organisations and *airline operated*/*owned* MRO organisations [8], 10-11]. The MRO industry has evolved over the years from when the majority of MRO activities were purely carried out by *airline operated*/*owned* MRO organisation [8]. In some cases, approval was given by the OEM to carry out these MRO type operations for components still under a valid warranty. The eventual parts and labour cost of any such repair or overhaul was then invoiced to the OEM [12]. However, following deregulation in the US in 1978, many airlines just entering the industry did not have existing MRO facilities or spare parts inventory(ies) to support their fleet [13]. The growth of these new low cost carriers encouraged the entry of *independent* MRO providers who offered relatively low-cost services ranging from line maintenance to inventory control. In an effort to cut costs, several of the established airlines, such as British Airways and American Airlines, began outsourcing more of their MRO activities to *independent* MRO organisations. This allowed managers to leverage resources and capabilities by concentrating on core competencies that create value for the airlines' customers, with non-value added activities being outsourced [8].

Establishing an airline MRO process is considered to be capital intensive which *smaller* and newer airline carriers may not be able to commit to. Low fare carriers with traditionally streamlined business models have avoided strategies adopted by major airlines of investing in large maintenance stations, but instead, have opted to outsource most MRO-type operations (especially heavy duty maintenance) to *independent/third party* MRO providers [10-11, 13-14]. In contrast, *bigger* airline operators prefer to retain a presence in this field [8]. The advantage of this choice is that Legacy carriers can compensate for the varying passenger volumes by offering MRO type services to other airlines [15].

An example of an *independent/third-party* MRO organisation is AAR Corporation. AAR is the second largest independent provider of MRO services in North America and its operations range from aircraft and engine support to engineering, logistics and precision fabrication capabilities. AAR provides both stand-alone services and customised, integrated solutions offered through unique combinations of diverse products and services. Conversely, Lufthansa has over the years boosted its maintenance arm (Lufthansa Technik) and has seen a steady growth in its MRO capabilities. Similarly, the joint venture between Air France Industries and KLM Engineering & Maintenance has also experienced tremendous growth with regards to its MRO capabilities hence retaining as much of the maintenance functions for its fleet in-house as expected of a typical *airline operated*/*owned* MRO organisation.

2.2.3. Introduction of *'Servitized'* (OEM) business models

Nowadays, there is a growing trend for OEMs to adopt *'servitized'* business models and thus offer an array of support packages directly to the customer. Servitization is traditionally described as the shift by manufacturers from selling the product alone with a few essential services to using services as a basis for competitive strategy [16]. With more value generated with increased *interaction* with the customer (Wise and Baumgartner, 1999), OEMs are offering packages that extend beyond the warranty of purchased products to include a complete service package that deals with the maintenance, servicing and spare-part replacement over a fixed time period. These support packages range from Bundled Asset Management Programmes (BAMP) to Integrated Customer Support (ICS) [11]. An example of such support or service offering includes **'TotalCare'** offered by Rolls Royce [18] and **'GoldCare'** offered by Boeing [19]. These packages essentially integrate engineering and planning services at a predictable and competitive cost with enhanced economies of scale. With packages such as these, OEMs are beginning to take up major stakes in the maintenance budget of airlines thus adding to the paradigm shift in the way maintenance is been viewed within the aviation industry. This also supports the proposition that more interest is not only given to *how* the maintenance service is carried out but *who* carries this out.

Although this trend of asset management and asset management engineering are only an emerging concept in the aviation industry, it is more prevalent within the aviation manufacturing community (OEM) than the traditional MRO organisation. However, there is a general trend of MROs owning assets that are used to support airline operators whilst their product is being overhauled. This suggests that typical MRO operations extend beyond what happens in the factory to the direct interaction with the customer also extending the scope of the application of Lean. Furthermore, due to the nature of these asset management programmes, OEMs have restructured their capabilities and MRO requirements resulting in a business operation that is slightly different from the traditional MRO organisation. This new context albeit still within the MRO sector, presents another opportunity for the application of Lean philosophy. However, this new context was beyond the scope of this paper.

With the growing popularity of these support packages where OEMs are offering MRO-type services, the study into the adoption of Lean can be extended beyond the typical MRO facility to also include its adoption in MRO-type *operations* within the aviation industry. However, the study presented in this paper was focused on the adoption of Lean within typical aviation MRO facilities.

2.3. Challenges to MRO Business Operations

Over the years, the nature of the challenges faced by the MRO industry has changed dramatically. The initial challenge for the MRO industry was purely '*production goals*'. These goals were driven primarily by the concentration on core competences. Almeida [13] demonstrated how *airline-operated* MRO organisations tended to be 'most competitive' within the early years of product manufacture because of their substantial inventory and geographic presence, which gave them the ability to serve customers around the clock. However, in the later stages of the life cycle of parts the economies of scale, obtaining licenses from OEMs to maintain and repair specific systems and specialising in state-of-the-art inventory control measures to reduce costs, favours *independent* MRO organisations. Although the life cycle of the product(s) to a large extent dictated *who* was most likely to carry out the maintenance operation(s), based on their core competence, the main challenge however, was purely focused on production goals.

The overall challenge for the MRO industry is now very different. The ever changing market forces now require that apart from the initial *'production'* goals, MRO organisations need to increase the margin between stock and value by considering every possible resource to maximise operational efficiency and minimise effort i.e. optimise and streamline business operation [20]. This means that the aviation MRO industry has to manage effectively how it minimises overall maintenance costs, reduces aircraft turn-around times (TAT) and establishes return on experience in the form of accurate job standards. MRO organisations also find that they have to contend with wildly varying asset types and configurations more than ever before. Maximising the facility capacity and ensuring compliance with the customer's maintenance program is another major issue within the MRO aviation industry [21].

There are consequently many initiatives to improve enterprise-wide productivity as increasing productivity has a universal appeal to any manufacturer faced with increasingly intense global competition [22]. Detailed study into the Lean paradigm led Womack *et al.* [23] to argue the position that Lean principles are applicable to any industry, a proposition that was supported by Haque [5].

The argument for the adoption of Lean is usually made considering the remarkable commercial performance of Toyota. It is important to point out that the success and discovery of Lean principles within the Japanese automotive industry was during a severe economic climate [22] similar to the current 2008/2009 global economic meltdown. At the end of 2003, Toyota published profits of 8.3 billion US dollar; greater than the combined profits of General Motors, Chrysler and Ford establishing Toyota as one of the top three car sellers in the USA [24]. According to company figures, Toyota in 2007, sold 2.348 million units in the US (the world's largest car market) with General Motors selling a total of 2.26 million.

Contrary to popular perception, many characteristics of Lean techniques were first recorded at the Ford production plants in the 1920s as documented by Henry Ford himself in his books '*My life and work'* [25] and '*Today and tomorrow'* [26]. Ford demonstrated the need to focus on the activities that are of service to the customer and wherever possible reduce the waste of material time and motion. However, the term 'Lean' itself was popularised by Womack and Jones [27] after careful consideration of the Toyota production operation. This study was sponsored by the International Motor Vehicle Program (IMVP) as part of a worldwide auto manufacturing benchmarking study. In 1996, Womack and Jones published the book '*The machine that changed the world'* [27]. This book helped to demystify the Japanese auto manufacturing techniques initially referred to as the Toyota Production System (TPS) showing its manufacturing superiority.

It is however important to point out that modern references to Lean thinking have variations in content and perspective [28]. The disparity ranges from the Japanese industries that tend to focus on Lean *'philosophy'* and *'culture'* compared with their western counterparts who tend to put more emphasis on the *'tools and techniques'* of Lean. The disparity in the perspective of Lean into these two divides has led to discussions of which one is more accurate.

Baines *et al*. [7] suggested that the philosophical approach is '*multidimensional'* in the sense that it involves the entire organisation in every function and encompasses a '*wide variety of management practices including just-in-time (JIT), quality systems, work teams, cellular manufacturing, supplier management etc. in an integrated system*'. Based on this definition, he concluded that it is no co-incidence that the Japanese companies who approach Lean implementation in this manner record greater successes than their western counterparts. Literature study also shows that the benefits of Lean cannot be realised simply by adopting a few tools and techniques. Intriguingly, most western manufacturers are focusing their Lean initiatives on operations with few attempts to adopt Lean as a culture. Whatever the perspective, neither of the positions is more correct than the other, since Lean exists at all levels both practical and theoretical [29]. The aim of Lean however, is to reduce all forms of waste (*'muda'*) as identified by Ohno [30] in order to improve productivity and enhance overall customer value. With this is mind, this paper will be careful in distinguishing between both perspectives '*Lean thinking*' and '*Lean principles*' in areas where their understanding and intent is crucial. However, in areas where their intent and understanding is not crucial and to reflect popular usage, this paper will refer to both perspectives simply as '*Lean'.*

The express approval and success record of Lean in the automotive industry has signalled other industrial sectors to awaken to the immense benefits that this philosophy has to offer [31]. Within the aviation industry for example, some MRO firms have been able to cut TAT dramatically by employing tools that relate to Lean principles. The most important factors in an airline's selection of an MRO supplier are typically quality, TAT and price, in that order. However, special circumstances can shift customer priorities which could mean that the priority changes. For example, an airline could have a situation where there are temporarily more aircrafts than needed to deliver its schedule thus giving TAT lower priority. But for a fleet sized right for its network, a short TAT is key to minimising total maintenance costs. The progress in reducing TAT should prove to be a strong competitive advantage [32].

Conversely, in an environment where quality and safety standards are tightly regulated, there is the concern as to whether all the principles of Lean philosophy are viable in this context. Since the main objective of the MRO industry is to restore the aircraft back to a state where it can safely perform its design functions, a process which can be loosely referred to as *'re-manufacturing',* there is the assumption that all of the principles of Lean can be implemented within this context. However, there is not enough proof in current literature to confirm this assumption. Hence, the study described in this paper is targeted to investigate the extent of the adoption of Lean principles and its philosophy within the aviation industry particularly within the MRO sector.

3. Research Programme

3.1. Aim, Scope and Research Questions

The aim of the research presented in this paper has been to identify and review available literature on the subject of Lean within the aviation MRO industry and thereby establish the state-of-the-art in this field. However, with the adoption and application of Lean within the MRO sector still in its formative years, the scope of this study was broadened to the application of Lean within 'maintenance' and 'service-based' environments. Discretion was then employed in making sure that the literature review that contributed to the success of this study was closely related to the aerospace/aviation MRO industry.

The research questions that served as the framework of this study were:

- How is Lean interpreted within the aviation MRO industry?
- To what extent has Lean been adopted within the aviation industry?
- What strategies have been employed in the adoption and sustenance of Lean?
- What are the inhibitors and enablers to the adoption of Lean?
- What are the strengths and weakness of existing literature?

With the understanding that the above questions may not result in major key findings or that there may not be specific sufficient literature to make decisive conclusions; they serve as the guide for the purpose of this study. All observations and notable points are briefly summarised in the following text.

3.2. Search Strategy

The approach to the search strategy started by first identifying the relevant data sources, the timeframe to be considered and the keywords. Initially, a broad selection of databases was identified covering journals, conference proceedings, theses, books, and articles from trade journals examples of which include EBSCOhost, Scropous (Elsevier), ABI/Inform (Proquest), Compendex, Inspec, and Emerald. Through these databases, a host of relevant sources of information were discovered such as the *'European Journal for Operational Research', 'Journal of Engineering Design', 'International Journal of Automotive Technology', 'Journal of Education for Business', 'International Journal of Productivity and Performance', 'International Journal of Operation and Management', 'Journal of Engineering Manufacture', 'Journal of Quality in Maintenance Engineering', 'Journal of International Economics'.*

In order to restrict the search to more recent publications, the timeframe for this study was chosen initially to include only literature published in the last decade (1999-2009). However, this time restriction was relaxed as the research progressed firstly by widening the timeframe beyond the last decade to the early nineties and then by evaluating earlier publications cited in literature.

Identifying relevant literature then required the use of an array of keywords which were carefully combined to obtain a host of articles and publications. Keywords like *'Lean', 'Maintenance Repair', 'Maintenance and Overhaul', 'Case Study', 'Toyota', 'Aviation', 'Supply Chain', 'Outsourcing' 'Aerospace'* and *'Airline'* were used and combined to identify a number of search strings as shown in Table 2. Some wildcards were also employed to increase the number of articles found such as '*Aero*', 'Manufact*'* and '*Maintenance Repair Op**'. The intention of these wildcards was to capture articles with spelling variances published in either 'UK' or 'American' style English and to capture articles with similar inference and conclusions but with different titles. For completeness, an Internet search was also conducted using similar techniques and processes as alluded to the library databases. Duplicate records identified by the various search strings were then eliminated. Abstracts of the remaining records were then reviewed as the final criteria in selecting the articles that would be relevant to the scope of this research. A brief review of MRO organisations with Lean implementation programmes (or similar incentives) was also carried out. Although the review carried out was peripheral in nature in that most of the publications were from internal magazines, a total of 6 companies were shortlisted as shown in Table 3 for the purpose of this research.

Search String	Keywords	Total Publications*
S1	Lean + Maintenance	166
S2	Lean + Maintenance + Repair	127
S3	Lean + Maintenance + Overhaul	97
S4	Lean + Maintenance + Repair + Overhaul	36
S5	Lean + MRO	91
S6	Lean + Maintenance + Repair + Operation	39
S7	Lean + Maint*	194
S8	Lean + Aero*	174
S9	Lean + Aviation	126
S10	Lean + Repair + Operation	43

Table 2: Literature keyword search results

Organisation	Method of Research	
	Website	Publications
Lufthansa Technik	✓	✓
Boeing	✓	✓
FedEx	✓	✓
British Airways	✓	✓
Exide Battery (Kansas)	✓	✓
Messier Dowty	✓	

Table 3: Identified MRO organisations with Lean Implementation Process

3.3. Results and Analysis

With the generic nature of this subject a huge amount of publications associated with Lean was initially identified. Out of all of the publications found, Table 4 shows a sample of the articles that were shortlisted for further review. The first criterion used in the selection of these articles was based on their relevance to Lean (tools, techniques and philosophy) in establishing a conceptual understanding of subject. An example of such an article is "*Learning to Evolve; a review of contemporary Lean thinking*" by Hines *et al* [28]. The second criterion used was the article's relevance to the aviation MRO industry. This led to a fewer number of relevant articles, as for example Mathaisel [21] - "A lean architecture for transforming the aerospace maintenance, repair and overhaul (MRO) enterprise".

Following a review and cross-referencing of the publications that were retrieved, it was established at the time of the search that 60 articles were suitable for the scope of this research which satisfied the timeframe and relevance. The review of these documents involved a brief summary of each of the publications against the initial research questions. An outline of the main topics covered by each publication was then compiled including the emerging themes observed. A critical review of all the publications was then carried out in order to capture and represent the consistency and variance in literature which are presented as key findings in the content of this paper.

The findings presented in this paper were tested by academia and practitioners to ascertain the authors' interpretations of the publications and the accuracy of the terminology used. On this basis, the following key findings were developed.

Author	Title	Source
Baines *et al*, 2006.	State-of-the-art in Lean Design Engineering: *A literature review on White collar lean.*	Journal of Engineering Manufacture (IMechE, Part B)
Haque, 2003	Lean Engineering in the aerospace industry	*Journal of Engineering Manufacture*
Andrew *et al*, 2008	Self Maintenance works for repair firm	*Journal of Engineering and Technology*
Al-Kaabi *et al*, 2007	An outsourcing decision model for airlines' MRO activities.	*Journal of Quality in Maintenance Engineering*
Mathaisel, 2005	A Lean architecture for transforming the aerospace Maintenance Repair and overhaul enterprise.	*Int. Journal of Productivity and Performance*
James-Moore and Gibbons**, 1997**	Is Lean manufacturing universally relevant? An investigative methodology.	*International Journal of Operations & Production Management*
Alejandro and Serebrisky**, 2006**	Competition regimes and air transport costs: The effects of open skies agreements**.**	*Journal of International Economics*
George and George, 2003	Lean Six Sigma for service: How to use Lean speed and six sigma quality to improve services and transactions	McGraw-Hill Professional, New York

Table 4: Key publications identified

4. Generation of Key Findings and Issues

The analyses of the literature review carried out provided the basis for the following key findings and issues.

4.1. The interpretation of Lean within the aviation MRO industry

There is a strong argument that the application of Lean principles alone to achieve the organisation's goal i.e. to improve the economic performance of the company and the optimisation on the Return-On-Investment-Capital (ROIC) is mere wishful thinking [33]. This argument is premised on the opinion that Lean principles alone cannot adequately bring a company's processes under statistical control nor can it define a sustaining infrastructure of its implementation [33]. With this perception of Lean it is no surprise that many MRO firms are implementing Lean principles in combination with other business strategies in a bid to achieve the enterprise set goals. An example of such a combination is the *'Lean'* and *'Agile'* approach. The integration of these two strategies as described by Andrew *et al* [3] is based on the advantage that '*Agile*' processes when introduced into the organisation would help in dealing with the issues of volatility in the market which makes forecasting difficult with irregular demand patterns, characteristic of the MRO industry. Andrew *et al* [3] further explains that many practitioners have attempted to integrate the two approaches by proposing what is referred to as the *'leagility'* and *'agilean'* approach. This integrated approach was developed to create a Lean yet highly responsive operational system beneficial to MRO organisations dealing with the consequences of globalisation.

More recently, 'Six Sigma' has been regarded as a successful system capable of achieving significant gains in business performance. Apart from the strength that it has in the focus on quality and the ability to more adequately bring an enterprise process under statistical analysis, many regard Six Sigma as a business strategy while others refer to it as a well structured and highly effective methodology that achieves improvements in product and process variation which in turn enhances operational performance [34]. Companies such as Motorola and General Electric have implemented this approach (Lean principles and Six Sigma) to great success and have based their Business-Process-Improvement (BPI) around the Six Sigma concept and to good effect. Smith *et al,* [35] explains that *Lean* brings action and intuition to quickly pick the low hanging fruit with kaizen events while *Six Sigma* uses statistical tools to uncover root causes and provide metrics as mile markers and concludes that a combination of both provides the tools to create ongoing business improvement.

The emergence and popularity of these hybrid Lean versions within the aviation industry has led to the conclusion that:

Finding 1

Lean is widely interpreted as a viable tool within the aviation industry albeit not sufficient by itself to realise all the goals set by the organisation.

4.2. The Focus of Lean

Mecham [36] stresses that although the principles of Lean implemented to great success in the manufacturing world are similar to those of the maintenance industry, there still remains scepticism about its focus. The cynicism conversely lies in the thought that the earlier exists in a manufacturing environment and the later exists predominantly within a service environment (albeit product-centric) and therefore it is not easy to directly transfer either's perception in their approach to Lean.

Furthermore, the introduction of Lean into the aviation MRO industry has led to the coining of the term 'Lean Maintenance' to capture the application of Lean to the industry [35, 37]. Yile [37] delineated the different phases and their corresponding focus in their interpretation of Lean maintenance. The different expressions range from a focus on increasing up-time and reliability to reducing operational cuts to the bare minimum. Other expressions of the focus of Lean incorporated overlapping Lean tools in order to reduce waste. Although there is the indication that MRO organisations are now beginning to see value creation potential in Lean application, this however, is not prevalent within the industry [38]. Whatever the expression, the underlying focus for the application of Lean currently is essentially, the reduction of waste [35].

Andrew *et al* [3] suggested that with OEMs employing Lean tools and techniques to build more reliable equipment requiring less servicing and increased time-between-overhaul (TBO), the need for customisable MRO work and cost pressures by airlines to have lower service costs and less aircraft downtime is significantly increased. They suggested that more OEMs are opting for the use of Lean tools and techniques in the pursuit of '*value creation'* as compared with the MRO industry where Lean is presented as a tool for achieving the main aim of '*reduction'* of waste.

With Baines *et al* [19] highlighting the danger of crossing and misinterpreting ideas put forward by Lean especially when the paradigm between the principles, tools and techniques associated with Lean have not been properly established, this has led to the conclusion that:

Finding 2

The focus of Lean within the aviation MRO industry is predominantly directed towards *waste reduction* as opposed to the creation or the enhancement of *value*.

4.3. The extent of the adoption of Lean within the aviation MRO industry

Haque [5] argued that although the aerospace industry was initially reluctant to the adoption of Lean, it is fully viable within the aerospace industry. Although Lean is gaining popularity within the aerospace industry and can be implemented in small and large companies alike, there is still a lack of sustainable methodology as well as proper application of supporting management tools and technology. This may be attributed to the fact that Lean has only recently been seen by the aerospace industry (particularly MROs) as a viable tool to improve the overall performance of the company [21]. The paucity of literature on the subject of Lean within the MRO industry serves as evidence of the industry's initial reluctance to its adoption compared with other industrial sectors.

Although the MRO business is vulnerable to both global and local market fluctuations, the specialised nature of the industry requires that its general internal structure is defined and conventional which is favourable for the adoption of Lean. The challenge however is that although significant strides have been achieved in the adoption of Lean, the extent of its adoption and the maturity across the whole MRO industry cannot be ascertained. Literature suggests that quite a lot of companies have embarked on their Lean journeys since the late 1990s, however, the spread of its application is significantly smaller in comparison to other industrial sectors especially the automotive industry [38-40]. This has led to the conclusion that:

Finding 3

There is strong emphasis on the adoption of Lean within the MRO industry, although the extent of its adoption is difficult to ascertain.

4.4. Strategy for the implementation and adoption of Lean

Pettersen [29] after successfully confirming the validity of the Lean paradigm, stressed that the overall goal of an organisation will be responsible for the way in which the concept is approached. Although he identified that there are generally two different types of goals: *internally* focused goals [24,41] and *externally* focused goals [42-43] he also stressed that the formulation of goals is essential to the Lean implementation approach. The lack of a precise definition and goal formulation will lead to difficulties in determining whether changes made in an organisation are consistent with Lean principles or not and this will subsequently lead to difficulties in measuring its effect and effectiveness [44].

Literature review reveals that different approaches have been adopted in Lean implementation programmes within the aviation MRO industry which complements the findings by Pettersen [29]. For example, Lufthansa Technik in its implementation journey has adopted a strategy similar to the *Kaizen Blitz* approach [45] which has recorded great success in its formative years. They have internally interpreted the Lean concept and developed a three phase approach to its implementation: '*Technical Systems'* (Lean tools and techniques), '*Management Infrastructure'* (monitoring and continuous improvement measures) and '*Attitudes and Abilities'* (aligning the working culture and mentality with Lean philosophy i.e. paradigm shift) [46].

Mathaisel [21] postulated a 'transformational' approach to the adoption of Lean within the aerospace MRO industry. After careful consideration of different approaches including the *design-build* approach proposed by Pearce and Bennet [47], and the *Kaizen Blitz* approach proposed by Laraia *et al*., [48], Mathaisel proposed the *Lean Enterprise Architecture* (LEA) implementation programme. He described it as a "*structured sequence of activities for the transformation of the MRO enterprise from a current state to a desired future Lean condition by using phased system based on transformation life cycle".*

Conversely, Fedex have adopted a different implementation strategy by completely redesigning its Los Angeles Airport facility in order to deal with the challenge of reducing cost and the need to boost revenue. The focus at the facility was to use Lean principles to increase its capacity using the same equipment and staff [49].

In many contexts, Lean success is often times regarded as the existence of a "Kaizen culture". However, this point was discredited by Roper [50] on the assumption that there is no roadmap for achieving this kaizen culture and without proper control; most organisations will run out of time and patience before they discover this path to leanness. Maithaisel [21] also explained that benchmarking oneself against best internal operations or against external direct competitors or against best external functional operations or against other generic functions regardless of the industry can be one measure of the value of one's relative leanness.

Although these organisations have recorded significant progress and profits that can be linked to their Lean implementation programmes employing several strategies, with everyone left to their own devices on their Lean journey the effectiveness and correctness of many Lean programmes will become questionable. This is because the numerous implementation strategies suggest that the overriding objective(s) and moderating factor(s) that ensure the successful implementation of Lean within MRO organisations is yet to be defined. This has led the authors to conclude that:

Finding 4

Various implementation strategies have been employed in the adoption of Lean, however, the moderating factors for its successful implementation remain unclear.

4.5. Inhibitors of Lean within the MRO industry

There is no doubt that the whole of the aerospace industry is now warming to the benefits and opportunity that are proposed by Lean to eliminate *'waste'* within its operations and the Lean revolution is underway within the industry [40]. However, there are some contextual factors that have inhibited the application and advancement of the Lean paradigm within the aviation industry. With very little published information on the challenges of Lean within the MRO industry, the following key inhibitors identified from literature review reflect the inhibitors of Lean within the aviation industry as a whole.

4.5.1. Comprehensive understanding of Lean

Crute *et al.* [40] suggested that the lack of comprehensive understanding in the interpretation of Lean served as an inhibitor to the early adoption of the Lean paradigm within the aviation industry. They suggested that one of the earlier misconceptions that inhibited the transfer of Lean from the automotive industry to the aviation industry was the challenge of adapting Lean from an industry of high-volume capacity (automobile) to an industry of low-volume capacity (aircraft). However, Womack *et al* [27] provide a detailed account of the introduction of Lean principles within Pratt & Whitney thus validating the aerospace sector as a suitable environment for the application and success of Lean. They also suggest that the aerospace industry may be at an advantage over automotive in the application of Lean principles, on the basis that lower volume capacity infers a closer association to the Lean ideal of single piece flow.

Another major misconception of Lean that inhibited the application and advancement of the paradigm is the confusion that arose from the different Lean capabilities across countries, from firm to firm but more so within firms. The differing interpretation of Lean led Crute *et al.* [40] into a case study research with the conclusion that Lean capabilities are '*plant'* specific. The uncertainty surrounding the interpretation and understanding of Lean contributed both to the reluctance to its adoption and/or the success of many Lean implementation programmes within the aviation industry. Pettersen [29] also came to the similar conclusion that the capabilities of Lean have to be fully understood and appreciated before any successful implementation can be achieved.

Lean production requires a change in attitudes and behaviour not only of managers but also of employees [51]. While the aerospace sector may have some advantages in implementing Lean, the challenges of implementation are real and prove difficult for many firms. Karlsson and Ahlstrom [52] suggest that traditional ways of thinking and practices are difficult to shed and radical change would be difficult and require an immense amount of effort to overcome. The introduction of Lean into an organisation will in most cases translate into the change of the existing working *culture* to one where the employees themselves look for potential problems, seek out and eliminate waste, and take responsibility for continuous improvement, quality assurance and maintenance. Bamber and Dale [51] suggest that the lack of a concise understanding of Lean by all employees will somewhat inhibit the advancement of Lean in organisations where it has been adopted or increase the reluctance of other organisations to adopt the philosophy. Consequently, it is important for researchers and practitioners to develop a comprehensive understanding of the Lean paradigm in order to demystify the myths surrounding Lean that have inhibited its adoption and successful implementation [53].

Finding 5a

The lack of comprehensive understanding on Lean and its capabilities is evident within the aerospace industry thus hindering the successful *adaptation* of Lean to be plant specific.

4.5.2. Inaccurate Forecasting and Uncertainty in Operations within the MRO Industry

It is also not uncommon for some of the technology in avionics and weapons systems to be outdated much earlier than expected either because suppliers cease production of some of these parts due to cutbacks in procurement (e.g. military) or in order to pursue higher-demand and more profitable commercial opportunities [54]. Similar logic also applies to the issue of *difficult-to-find* parts [53]. Due to the difficulty in accurately predicting these scenarios, decisions have to be made by MRO organisations to hold some of these components in excess inventory earlier on in the product's life cycle [55]. With excess inventories held by many MRO firms, there seems to be a contradiction with the ideals of Lean as discussed by Ohno [30].

Also, with high labour rates forcing the majority of aviation MRO type logistics carried out in Europe and North America to move to lower wage countries particularly to Asia, Eastern Europe and Central America as a way of reducing cost, the associated supply chain process supporting the MRO industry becomes more complicated [11]. To minimise the issues that come with complex supply chains, the majority of MRO organisations tend to hold excess levels of inventory.

In other instances where excess inventory is not kept, the inherent variability of repair work unlike repetitive manufacturing is impossible to precisely forecast until a full inspection is accomplished. However, upon inspection of an unserviceable aircraft, the “unpredicted” or “emergent” rework or damaged parts found will then have to be ordered on an expedited basis [10]. The danger inherent is that these uncertainties result in delays which could disrupt the original schedule and final delivery of the overhauled items. In order to overcome these challenges, it is not unusual for MRO organisations to hold more than the required inventory which again contradicts the ideals of Lean as explained by Ohno [30].

Finding 5b

The difficulty in accurate forecasting, typically characteristic of the aerospace MRO industry, results in practices which contradict the ideals of Lean thus serving as an inhibitor to its adoption and or its advancement.

4.6. Motivation for the adoption of Lean

Although there were and still are challenges in the interpretation of Lean within the aviation industry, Womack and Jones [27] was able to establish that Lean is viable and suitable in this industry. Whilst the drivers and motivators for the adoption of Lean within the aviation industry have changed over the years, the main factor(s) that consistently enables its suitability and successful implementation within the aviation MRO industry is concealed in increased business pressures and globalisation.

The need for improving operational performance in the MRO industry is intensifying [4].

The increase in globalisation has clearly necessitated a complete rethink for some firms in terms of how they can organise and reconfigure themselves [40]. These business pressures infer that MRO organisations not only have to continually evaluate and cut TAT to be able to compete within the global market but also to cut internal cost i.e. doing more with less and subsequently, improve customer asset availability. MRO organisations are therefore searching for solutions to dramatically improve performance and enhance their competitive advantage.

The true motivation and enablers of Lean within the aviation MRO industry are measured against the perceived benefits they offer. These benefits are usually associated with the time, productivity, efficiency, space, quality, people and cost savings. However, Shah and Ward [56] suggest that most of the empirical studies focusing on the impact of Lean on operational performance are constrained to one or two facets of Lean i.e. JIT or TQM. Notwithstanding, a recent Lean Aerospace Initiative study by MIT [57], found that the introduction of Lean led to approximately 10-71 percent improvement in labour hours; 11-50 percent improvement in cost; 27-100 percent improvement in productivity; 25-81 percent improvement in factory floor space and 16-50 percent improvement in customer lead time. Other benefits included 31-98 percent improvement in inventory or work in progress (WIP) and a scrap/rework/defects/inspection improvement of about 20-80 percent. All of these benefits are indicative of the motivations for the adoption of Lean in the Aviation MRO industry.

As a result of these factors a number of major players within aerospace are pursuing Lean practices [40, 58]. It is no surprise that more and more MRO firms are turning to the same philosophy that ensured the survival and growth of the Japanese automotive industry when faced with similar challenges.

Finding 6

A major driver for the adoption of Lean is based on the assumption that MRO business pressures are consistent with what *Lean* can deliver.

4.7. Critical Success Factor for the Implementation of Lean

The '*pressures'* forcing the MRO industry to turn to '*Lean'* as a saviour are tangible [20]. Andrew *et al.* [3] suggest that in order to successfully compete on a global scale, there should be a clear and novel way by which MRO process strategy tackles the real issue of improving operational facility performance and reduce variation in key-performance-indicator attainment that achieves long-term economic sustainability. As already established by Karlsson and Ahlstrom [52], a company does not achieve Lean product development simply by implementing Lean techniques alone, instead, a successful move towards Lean requires approaching these interrelated techniques in a coherent way. Successful Lean implementation will require the involvement of everyone up and down the ranks in the company as seen from both literature and case studies [7].

All of these responsibilities will require strong leadership skills. Literature [59] suggests that these responsibilities are driven by targets and deadlines. Therefore, the person(s) tasked with these responsibilities should have proven engineering excellence, leadership skills to control the programme and must be able to effectively interpret customer satisfaction into practical engineering practices and vice-versa within the scope permitted by the Lean paradigm [5, 24].

Finding 7

Lean implementation success is reliant on the key project management strengths and skills of the person(s) tasked with the responsibility of the whole project. Any successful Lean implementation programme will require the complete involvement of all staff.

4.8. Strengths and Weakness of Existing Literature

Haque [5] highlights the relative lack of the application of Lean within the aerospace industry. It therefore goes without saying that the extant literature on its application within the industry, particularly the MRO sector, will be relatively small. This could be as a result of the relative newness of the paradigm to the industry.

Furthermore, Crute *et al.* [40] came to the conclusion that the application of Lean is *plant* specific; a standpoint that Pettersen and Liker [29, 60] also subscribed to. They also highlighted the need for a comprehensive understanding of the paradigm before any successful implementation can be achieved. Although the aerospace industry as a whole has woken up to the possible benefits that could be reaped from Lean, many practitioners and company managers are still sceptical about the results and are thus, still piloting different adaptations of Lean. This scepticism and underlying lack of precise understanding and clarity on the subject may also lead to the paucity of literature on the subject pertaining to the MRO sector.

Conversely, there currently seems to be an aggressive implementation of Lean (or its variants) within the aviation MRO industry. This might have been exacerbated by the increased globalisation and global financial crisis of 2008/2009. This suggests that with the amount of attention given to Lean within the aviation industry, there will be a significant increase in the amount of relevant literature on Lean within the aviation industry particularly within the MRO sector in the near future.

Finding 8

There is a paucity of Literature on the adoption of Lean in the aerospace MRO industry.

5. Discussion

It is clear from literature that in order to mitigate the continuously increasing competition within the aviation MRO industry, many organisations are turning to Lean philosophy especially because of the benefits it is perceived to offer. This is premised on it success within the automotive industry. However these perceived benefits have to be clearly understood in the context of the environment where it is to be implemented.

Firstly, it has been established in literature that there is an increasing demand for reduced TAT from airline operators. This demand is sometimes even considered as one of the order-winning criteria especially when dealing with LCC who cannot afford the lengthy downtime associated with aircraft maintenance. However, attention also has to be drawn to the fact that, in most cases, only very limited information is known about the condition of the product before it is sent for overhaul. This therefore presents a puzzling situation where the customer has been guaranteed a delivery date for the overhauled product based on speculation about the condition of the product and consequentially, the required MRO operations and the associated time is not known. Although the ideals of Lean suggest its suitability within such an environment in that it is supposed to remove *wasteful* operations in the overhaul process, the huge uncertainties involved also point to the challenges that it must overcome for it to be considered as successful within this industry.

The inclusion of OEM in the MRO market through asset management programmes (servitization) introduces a new dimension to the competition. OEMs are able to install remote monitoring programmes to the product that provide up-to-date information on the condition of the product which enhances their competitive advantage. This also means that they *know* the maintenance operations that are required before actual receipt of the product. This informs their planning and supply functions, making it a more conventional environment for the implementation of Lean. However, this is a relatively new but growing phenomenon within the aviation industry and particular to certain sectors (engine). These genres of remote monitoring programmes are capital intensive and a luxury that most traditional MRO organisations cannot afford simply because of the huge investments and because the proprietary rights of the product still remain with the OEM or the airline operator. Therefore, this major and peculiar challenge of the industry presents a prospective area for further research especially with its interaction with Lean.

Furthermore, the context of its implementation also suggests that a thorough understanding of the Lean philosophy has to be achieved in order to ensure its relevance, effectiveness and sustainability within the industry. As identified in literature, there cannot be a direct transference of Lean principles from one industry (automotive) to another (aviation). This is not indicative of an inherent limitation of the Lean philosophy, but that the emphasis of its application in practice may differ between industrial sectors albeit having similar goals. A significant amount of current literature suggests that more clarity on the philosophy of Lean is still needed within the industry especially considering current focus and interpretation of Lean.

There is a growing proposition that Lean focuses on the creation of value as opposed to the elimination of waste. Although both motivations are closely linked, they could be misleading in practice. The creation of value infers a greater threshold for inefficiency in the production system as far as value is created whilst the focus of waste elimination holds a much lower tolerance for inefficiencies in the production system. This is also indicative of the clarity that is required on the adoption of Lean by the industry.

As pointed out in literature, all of these challenges present an exciting opportunity for Lean in this industry with some companies already reporting successes directly linked to Lean implementation. Although the extent of its application within the industry cannot currently be ascertained; the robustness of the Lean philosophy will be judged by its performance in this industry.

6. Concluding Remarks

This literature review as summarized in Table 5 indicates that Lean is viable within the MRO sector of the aviation/aerospace industry with significant benefits when applied to both *independent* and *airline operated/third party* MRO organisations alike. However, the various implementation strategies within the aviation MRO industry, and a distinct lack in the comprehensive understanding of the factors that contribute to the long-term success of its application, suggest that several Lean implementation programmes will become questionable over time. A comprehensive understanding of the Lean concept will help in validating the success of Lean as an independent tool in overcoming the challenges of the MRO industry.

It has also been established that the MRO industry is vulnerable to both external and internal demands and fluctuations (e.g. passenger volume, difficulty in forecasting and sourcing parts etc.), the interpretation of Lean has to be specific to the MRO industry and suited in a way that minimises the consequences of all these variables.

Although Lean in its simplest form is primarily focused on the reduction of waste, the associated support functions and the consequence of internal changes are yet to be established. This infers that the strategy for the successful implementation of Lean which considers all of the supporting *functions* is yet to be established.

There are also findings that expose the shortcomings of Lean. There is a general belief that Lean alone is insufficient to achieve a company's goals and thus has to be combined with other tools such as Six Sigma etc. This belief might either be as a result of the lack of understanding of the subject or an inherent fallibility of the paradigm itself. Whatever the case, the capabilities of Lean still require clarity especially in its adaptation to the MRO industry.

Literature within this field (i.e. Lean within the MRO industry) remains scarce compared to other industries where these principles have already been established over time. However, the surge of companies welcoming the Lean *idea* suggests that this will encourage more academic research providing better and accurate documentation of proven practices and methods for the successful implementation and the growth of Lean within this sector. The newness of this paradigm to the MRO industry means that many practitioners are still 'experimenting' with these principles and there is scope for further research into the *ideal lean framework for the aviation MRO industry.* This involves mapping out the most suitable implementation approach and customised measuring metrics to benchmark the success of its implementation. This will also involve developing a qualitative and quantitative system and/or methodology that sustains the successful implementation of Lean. There clearly is scope for future research in this area.

Topic	Key Finding/Issue
Interpretation of Lean	Lean is widely interpreted as a viable tool within the aviation industry albeit not sufficient by itself to realise all the goals set by the organisation.
The Focus of Lean	The focus of Lean within the aviation MRO industry is predominantly directed towards **waste reduction** as opposed to the creation or the enhancement of **value**.
Extent of the adoption of Lean	There is strong emphasis on the adoption of Lean within the MRO industry, although the extent of its adoption is yet to be ascertained.
Lean Implementation strategy	Various implementation strategies have been employed in the adoption of Lean, however, the moderating factors for its successful implementation strategy remains unclear.
Inhibitors of Lean	The lack of comprehensive understanding on Lean and its capabilities is evident within the aerospace industry thus hindering the successful adaptation of Lean to be plant specific. The difficulty in the accurate forecasting typically characteristic of the MRO industry results in practices that contradict ideals of Lean thus serving inhibitors to its adoption and or its advancement.
Enablers of Lean	A major driver for the adoption of Lean is premised on the assumption that MRO business pressures are consistent with what Lean can deliver.
Critical factor for successful Lean Implementation	Lean implementation success is reliant on the key project management strengths and skills of the person(s) tasked with the responsibility of the whole project. Any successful Lean implementation programme will require the complete involvement of all staff.
Strengths and weakness of Existing Literature	There is paucity of Literature on the adoption of Lean in the aerospace MRO industry.

Table 5: Summary of key findings and Issues

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State-of-the-art of 'Lean' in the aviation maintenance, repair, and overhaul industry

Ayeni, P.

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