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Towards the strategic adoption of Lean in Aviation Maintenance Repair and Overhaul (MRO) industry: An empirical study into the industry's Lean status

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Abstract:

(i) Purpose:

Despite many Maintenance Repair and Overhaul (MRO) organisations alluding their positive business performances to the adoption Lean initiatives, there is a paucity of direct literature that validates this assertion. Thus, contained in this paper is an empirical study via the use of an industry-wide survey to establish and extent of Lean adoption and to verify its suitability in mitigating prevalent MRO challenges.

(ii) Design/methodology/approach:

The empirical study contained in this paper is facilitated by an industry-wide survey to collect data from several firms across the MRO spectrum. The analysed responses from industry leaders, professionals and executives synthesised with existing literature was used in ascertaining the extent of Lean adoption within the operational framework of the industry.

(iii) Findings,

The empirical study helped in validating the suitability of Lean in MRO context. However, it was also observed that the focus of its application was skewed towards its production-orientated functions more than its service-orientated functions. Nonetheless, this paper presents results of the positive influence of Lean in MRO context.

(iv) Research limitations/implications:

This empirical study presented in this paper was carried out within a framework of key characteristics of operation. Although this approach is sufficient in assessing the industry's Lean status, further assessment can also be achieved within the context of relevant performance metrics which was not included in this paper.

(v) Originality/value:

Apart from validating the suitability of Lean in MRO contexts, by establishing the extent of Lean adoption within the context of the operational framework, this paper provides a clearer insight as to how successful Lean implementation can be achieved via a holistic implementation strategy balanced between the product-centric and service-centric aspects of the industry.

Keywords: Lean, Maintenance Repair Overhaul, Survey, Product-Centric.

NOTATIONS

MRO	Maintenance Repair Overhaul
OEM	Original Equipment Manufacturer
TAT	Turn-Around-Time

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1 INTRODUCTION

Lean production has been identified as one of the prevalent business strategies in the aviation Maintenance Repair and Overhaul (MRO) industry [1]. In a business environment characterised by intense global competition, demanding production goals along with changing market forces, there has been significant pressure on MRO organisations to increase profit margins whilst optimising and streamlining business operations [2]. This has translated into the aviation MRO industry having to manage more effectively how it minimises overall maintenance costs, reduces aircraft turn-around times (TAT) and establish return-on-experience in the form of accurate job standards. Conversely, these continuously changing market forces also mean that MRO organisations have to contend with wildly varying asset types and configurations now more than ever before. It is therefore no surprise that many MRO organisations have turned to Lean as a solution to improve enterprise-wide productivity especially because of its universal appeal as a successfully tried and tested model in the automobile industry [3].

Lean philosophy itself can be described as a multi-dimensional approach that encompasses a wide variety of management practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc. in an integrated system [4]. The core thrust of Lean production is that these practices can work synergistically to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste [5]. Although the principles behind Lean are not in themselves new as they date as far back to Henry Ford's production line; its adoption in the aviation MRO industry has only been recently emphasised [1].

The MRO industry can be described as the arm of the aviation industry that is primarily responsible for the retaining or restoring of aircraft parts 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 [6]. MRO activities are principally the servicing, repair, modification, overhaul, inspection and determination of condition of the aircraft especially at scheduled periodic checks. The main role of the aviation MRO sector is summarised as essentially responsible for the provision of a fully serviceable aircraft when required by the operator at affordable and reasonable cost with optimum quality [6].

The relatively late introduction of Lean (often referred to as Lean Maintenance in the aviation MRO industry) has motivated this study into how Lean 'works' in MRO contexts. However, with the paucity in literature directly relating to this subject area in the aviation industry, it became necessary to carry out more research that engages the industry to more accurately establish both the industry's perception of Lean and ascertain the industry's Lean status. An empirical approach was employed via an industry-wide survey that involved the participation of industry leaders, professionals and executives. Thus, presented in this paper is first a brief description of key features of the MRO industry that form the scope within which this empirical research was realised. The research design and the construct for the research questions are then introduced followed by the questionnaire design and administration. The results of the survey have been synthesized into a set of findings on the influence of Lean in the aviation MRO industry. Finally, the results of this survey is discussed and summarised with conclusions drawn.

2 Empirical Research Framework

From the definition of the MRO industry as summed up by Al-Kaabi [6] it becomes clear that the MRO *capacity* cannot be accurately defined solely within manufacturing or service terms alone as it seems to encompass aspects of both industries. For example, the conventional manufacturing industry could refer to MRO offerings in terms of its 'remanufacturing' functions; describing the main function of the MRO industry as responsible for the restoration of the product (aircraft) back to a state where it can perform its required design functions. Conversely, the conventional service industry could argue that the primary function of the MRO industry is to provide a 'service' in the form of aircraft maintenance to the aviation industry. It therefore follows that a compromise between the two perspectives may be more accurate in describing the MRO capacity. Therefore, it would not be out of place to refer to the aviation MRO industry as a 'product-centric service' industry; a description that seems to encompass elements of both the conventional Manufacturing and Service industries into one unit [7]. The MRO capacity is made up of different functions with some more closely related to conventional manufacturing (or production) contexts while others are more popular in conventional service environments. The combination and interaction of these different functions is represented by the 'Operations System' of the MRO industry which will be evident in typical MRO organisations.

The operation system of a company is based on the subtle blend of the 'transactional' and 'relational' activities [8]. These activities can also be represented as the production and service characteristics of the organisation. Production characteristics tend to be configured on conventional principles focused on the physical transformation of product into finished goods. By contrast, the service characteristics focuses on the interaction of the non-physical systems connected by similar value propositions as the production operations through facilitation and mediation. These production and service characteristics can be distilled and grouped into the 'Key Characteristics of Operation' of the business. It is within these key characteristics of operation that strategic business decisions are often made. It is therefore expected that the introduction of Lean into the MRO industry should influence the decisions that are made within these key characteristics of operation. Understanding the influence of Lean within these areas would not only help in assessing the extent of Lean adoption, but will be crucial in validating Lean's ability to mitigate typical MRO challenges.

Baines et al. [8] established a comprehensive 'Principal Model' that represented a framework of key operational characteristics including the production-centred framework advocated by Hayes and Wheelwright [9], Hill [10]; service-centred operation frameworks that were advocated for by Silvestro et al. [11]; Collier and Meyer [12]. Across these two groups, 11 distinct key characteristics of operations were identified and divided into Structural and Infra-structural characteristics based on their production and service orientations as listed in Table 1.

Structural characteristics	Infra-structural characteristics
Process and Technology	Human Resources
Capacity	Quality control
Facilities	New Product/Service Range and introduction
Supply Chain Positioning	Performance measurement
Planning and Control	Supplier Relations
	Customer Relations

Table 1: Characteristics of operation [8]

The achievement of 'Leanness' in a best-in-class company would largely be determined within the framework of these key characteristics of operation ([13], [14], [15]). The influence of Lean within these areas would be observable and as such, enable an assessment of the extent of Leanness in the different processes within an organisation. It is important to note that popular usage of the term 'Key Characteristics of Operation' can also be represented as 'Strategic Business Decision Areas' of the organisation and thus, both terms will be used interchangeably in this paper except where intent and understanding is crucial. For the purpose of this study, the identified characteristics of operation refer to the following:

1. **Process and Technology**: This key characteristic of operation largely represents the physical resources and technologies that are used within operations [8]. This deals with automated systems and varying range of technology, information systems and databases to enhance product conformance, efficiency, communication and customer interaction. It also deals with production (shop-floor) layout and processes. The challenge within the product-centric environments akin to the MRO industry is the ability to exploit a range of technologies throughout operations to achieve efficiency in production and effectiveness in service delivery
2. **Capacity:** This characteristic of operation deals with how production capacity should be matched to demand in order to ensure optimum resource utilisation [9]. The main emphasis

in this strategic business decision area is on the interaction between Human Resources, Technology and Supply Chain to match demand. For example, Baines et al. [8] suggests that product-centric service operations are characterised by multiple customer touch-points each of which can generate varying capacity demand signals necessitating differing forms of response from the host organisation. Thus, the fluctuating demand experienced by the MRO industry should suit multiple customer "touch points" that would foster the need to operate with differing levels of capacity utilisation.

3. **Facilities**: This key characteristic of operation typically deals with the choice of production sites, their location and specialisation [9]. For example, this study will be keen to explore if the MRO industry exploits economies of scale by bringing together and centralising production activities that maximise available resources to both accommodate and enhance customer experience [16]. This does not limit production to a single site. It is common for Product-Centric Service organisations to re-organise their business into networks of smaller business units or multiple field facilities within close proximity to the customer to aid quicker response and deliver an overall better service.
4. **Supply chain Positioning**: This covers the range of activities carried out by the company and how it relates to outsourcing, in-sourcing, subcontracts, Make vs Buy decisions. The positioning and control of an organisation's supply chain is dependent on its production footprint is usually centred on its core competencies. Product-centric service organisations typically tend to have control over the cost and quality by continuous vertical integration whilst positioning itself to become less dependent on broad in-house capabilities and thus engage partner organisation in delivering value ([17], [18]).
5. **Planning and Control**: This relates to the flow of materials in and through the company using different production planning models. More popular models include Enterprise Resource Planning (ERP), Materials Requirements Planning (MRP), Optimised Production Technology (OPT), Period Batch Control (PBC), Kanban. There is a focus on the optimisation of product availability and interaction between information capacity and stock ([10], [19]).
6. **Human Resources**: This refers to integration of the workers into the operation system. This involves the sub-division of labour and fragmentation of process with increased emphasis on worker skills, defined routines, training, motivation, attitudes, values and culture of the organisation in sufficiently satisfying customer requirements [20].
7. **Quality Control**: Efficient production operations have utilised Lean principles and techniques to control quality by achieving product conformance and the minimisation of waste in materials and resource usage [21]. This business decision area extends beyond the product to

include appropriate measures that improve on the customer's perception of acceptable service [8]. Examples of tools that have been employed in these areas include Statistical Process Control (SPC), Statistical Quality Control (SQC).

8. **New Product / Service Introduction**: This business decision area involves the configuration of the operation system to deal with the introduction of new product or services [10]. Although several methodologies for new product introduction are extensively discussed by many authors in conventional manufacturing contexts, common practice is to allow for ample test to be carried out before the product is released to the market ([1], [21], [22]); the testing and refinement of new services are carried out 'in the field' with the customer as they are usually tailored to customer expectations that may exist at different levels of consciousness ([23], [24]).
9. **Performance Measurement**: This refers to the performance measuring approach of the organisation. Although, traditional performance metrics are generally measured against Cost, Quality and On-time delivery; Product-centric Service environments also feature metrics that tend to use different customer and employee satisfaction and business success criteria ([25], [26] and [27]). This study will be keen to evaluate the influence of Lean in the area how it relates to the motivation for Lean adoption. These approaches may involve the use of tools such as machine utilisation, worker utilisation, WIP, Door-Door time.
10. **Supplier Relations**: This refers to how the operation system is configured in the sourcing of resources and materials. Effective management of the supply chain is critical for efficient and effective production operations [28]. To be effective, it is important to align supplier relations in both internal and external supply chains. Other approaches may involve single sourcing to multi sourcing or even the integration of external and internal supply chains. Whatever the approach, the responsiveness of supply chain in meeting customer expectations is critical
11. **Customer Relations**: This key characteristic of operation refers to the balance between the transactional aspect of production and the relational aspects of the operation system. Whilst the transactional aspects generally tend to focus on improving internal operational efficiency, it is crucial to pay equal attention to the relational aspect of the operation system in building and maintaining relationships with customers [29]. This study will also assess what influence of Lean has in the interaction between the MRO industry and the end customer (airline operators).

The major challenge for the MRO industry is the successful interpretation and implementation of Lean within the context of all these key characteristics of operation of the operation system. Investigating the influence of Lean in each of these areas would serve an appropriate measure of the industry's Lean status and provide more insight as to how Lean 'works' in aviation MRO context.

3 RESEARCH PROGRAMME

3.1 Research Aim & Objectives

The evaluation of existing literature suggests that Lean is being applied to some degree of success in the aviation MRO industry. Although, these allusions could not be accurately verified due to the paucity in literature, they serve as a general advocate for its adoption in typical MRO context. This served as the motivation for this empirical research into ascertaining the extent of Lean adoption and how it worked in aviation MRO contexts. With the guiding aim of understanding how Lean 'works' in aviation MRO context the following objectives were set:

1. Establish the extent of Lean adoption within the MRO industry
2. Profile the influence of Lean within key business decision areas of the MRO industry.

This was a largely inductive study, guided by a literature which informed the industry-wide survey. The research questions were grouped under the following themes:

Theme 1: *Lean adoption within contextual factors*

The influence of Lean within the identified key characteristic of operation will be vital in profiling the industry's Lean status. Not only will the synthesis of all the responses give an indication to the nature of decisions made but also, provide more insight into the respondents' awareness of their MRO capacity and how well they perform within those functions. This will further expose the industry's perception towards Lean and its ability to mitigate industry challenges.

This determination of Lean adoption will be also be realised in context of the production footprint of an organisation. The production footprint of an organisation is represented by its position on services, production and supply chain related activities that the organisation chooses to carry out or have control and ownership [30]. An appreciation of the production footprint of an organisation is not only vital in assessing the extent of Lean adoption within the organisation but it also exposes any linkages that may exist between the size of its operation and the drive for the adoption of Lean. The empirical study carried out by Shah and Ward [31] suggests that organisations with larger operational footprint are more inclined to implement Lean practices than their relatively smaller counterparts. This proposition would be checked in this empirical study.

Theme 2: *Impact of Lean on MRO output*

With the prevalence of Lean principles, it is important to understand the true motivation for Lean adoption and assess if this motivations are truly being fulfilled within the aviation MRO industry [30]. A Lean Aerospace Initiative study by MIT [32] into the auto-industry found that the introduction of Lean led to significant improvement in areas labour hours, production costs, productivity, customer lead times and a scrap/rework. Therefore, investigating these areas in the aviation MRO industry would confirm if Lean is suitable in the aviation MRO industry.

With the understanding that the responses to these questions are relative and are based on the opinions of industry leaders, the outcome of this study may not result in key findings; however, the above themes were used to guide this survey. All observations and notable points are briefly summarised in following sections of this paper.

3.2 Survey Design, Administration, Response and Analysis

The process tasks involved in the realisation of this empirical research included the following:

(a) Design survey questions informed by existing research reported in literature;

(b) Pilot and refine questionnaire, scope study, and target organisations;

(c) Execute survey; compile results, document, and publish results.

The survey was aimed at all the sectors of the MRO industry to avoid any bias ([33], [34]). Companies were identified through the International MRO Trade shows (UK 2010) and from the Aviation Weekly MRO database. Other organisations were identified using the FAME (Financial Analysis Made Easy) database. This breakdown is illustrated in Figure 1:

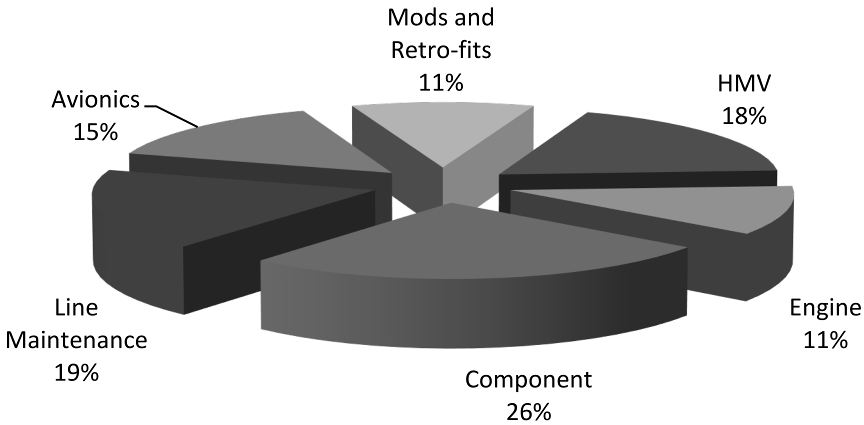

Figure 1: Survey response according to industry sector: Heavy Maintenance Visit (HMV); Engine Overhaul; Component Overhaul; Line Maintenance; Avionics; Major Modifications, Retrofits and Conversions [7].

The survey was based on a self-administered questionnaire typically addressed to managing directors. Paper copies of the survey were sent out in June, 2011 with responses collected over the following 3 months period.

The original target sample was about 136 companies with 22 fully completed questionnaires received. All these responses were from senior executives (e.g. industry leaders, professionals and executives). The response rate as calculated by the American Association of Public Opinion Poll Research was approximately 18 per cent. The critical evaluation of the responses confirmed initial literature review findings and provided significant insights into the perception of Lean within the Aviation MRO community.

4 KEY FINDINGS EMERGING FROM SURVEY RESULTS

The analyses of the responses provided the basis for the following key findings.

4.1 Assessment of Lean influence in key characteristics of operation

The survey set out to find out the impact of Lean within all the identified key business decision areas both Structural and Infra-structural. This interest is based on the preposition that successful implementation of Lean will be translated and filtered through all key characteristics of operation as listed in Table 1. The analysis of the response led to the following observations:

4.1.1 Structural Characteristics

Within the structural characteristics of operation, analysis of the responses indicates that Lean efforts have been most directed towards the *'Process & Technology'* key business decision area as shown in Figure 2. This strategic business decision area deals with the interaction between physical resources and the technology employed and thus, its parameters are more closely linked to conventional manufacturing environments ([9], [10]). This would involve the use of automated systems to enhance product conformance, efficiency, communication and customer interaction. The optimisation of the shopfloor layout to get the best out of these automated systems is also covered in this strategic business decision area ([35], [36]).

The extensive research that has been carried out within this characteristic of operation in the manufacturing sector provides substantial information that can be used in the application of Lean within MRO production. Thus, the positive outcome of Lean in this area is not hugely surprising. However, caution has to be taken in the transference of Lean from a conventional manufacturing shopfloor to an MRO shopfloor as they are different. The stochastic nature of MRO repair and rework is the fundamental difference with the conventional manufacturing environment. However, one can safely expect to see an increase in the automation of production systems in order to improve the quality conformance of the product. Also, the adoption of Lean manufacturing practices would also result in the batching of parts with similar pertinent process requirements so as to benefit from combined set-up time reduction ultimately leading to improvements in process flow. Consequentially, the need to improve process flow would also mean a re-evaluation of the shopfloor layout possibly based on part groups, families, or process requirements. Therefore one would expect a relative proportion of Lean efforts to also be directed towards the *'Planning and Control'* characteristic of operation.

As observed from the analyses of the synthesised results, Lean was also noted to have achieved relatively good success in the *'Planning and Control'* strategic business decision area. The success of Lean within the *Process and Technology* areas is relatively proportional to the positive outcome in this area especially as *Planning and Control* has to do with the optimisation of product availability and interaction between information capacity and stock ([10], [19]). However, it is interesting to note that although literature suggests that production *Planning and Control* activities are inherently more complex within MRO-type environments [37]; the application of Lean within other inter-related key characteristics of operation seems to have contributed to the increased success of Lean in this area.

As earlier explained, MRO *Planning and Control* is all the more complex due to market fluctuations (external), unknown and stochastic condition of products (internal). Thus, the popularity of more advanced production planning tools that focus on the optimisation of product availability and interaction between information capacity and stock such as Enterprise Resource Planning (ERP), Materials Requirements Planning (MRP), to simple tools Kanban Systems is a welcomed positive observation. However, it should be noted as shown in Figure 2 that the rating of Lean in this area is still somewhat lagging behind the *Process and Technology* suggesting that efficient balance between product availability, information capacity and stock is still yet to be reached.

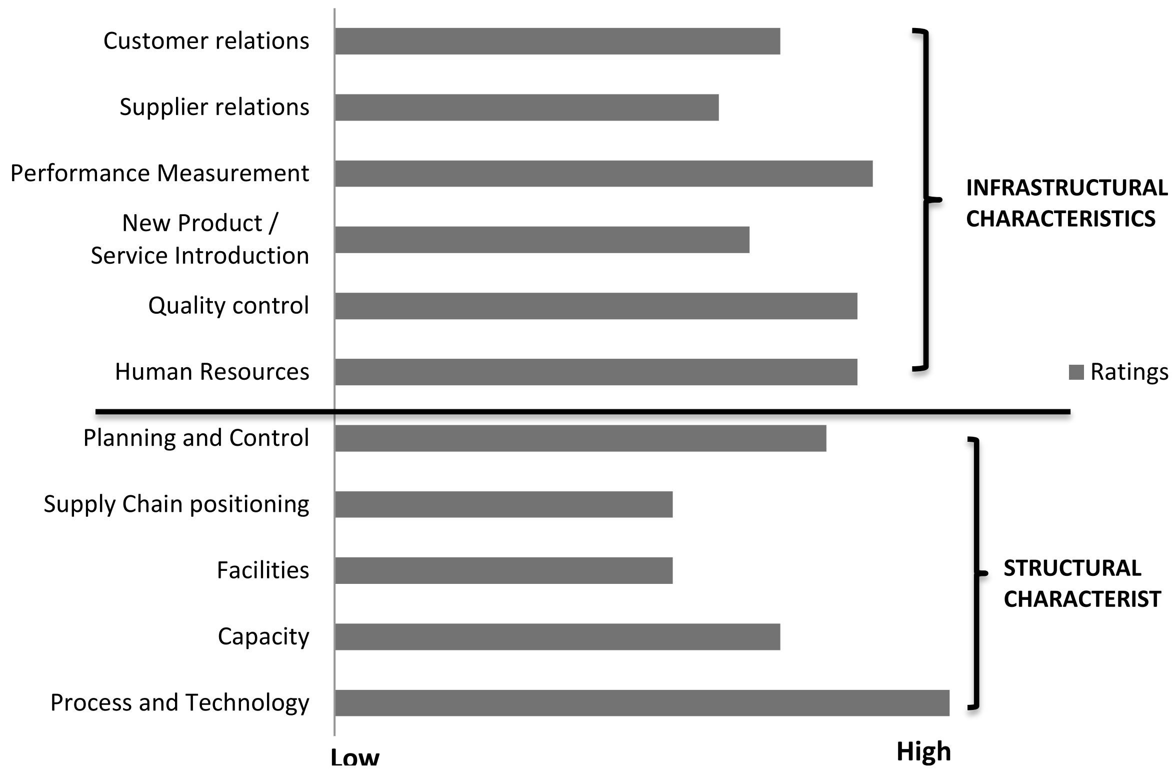

Figure 2: The influence of Lean within identified key characteristics of operation

Conversely, the application of Lean in the *'Facility'* and *'Supply Chain'* operation recorded relatively lower ratings as compared with other structural areas. The *Facility* decision area involves the proximity of the organisation to customers, suppliers and markets [8]. This characteristic of operation also influences the human resources, skills information and possibly finance that are available to the organisation. More importantly, this strategic decision area is critical in delivering agile and flexible support to the customer. With more global MRO support increasingly becoming a necessity for airline operators, the need to adapt to this evolving demand is an increasing necessity for survival and competitiveness. Current industry practice is that the global support required by the airline operators is still being expedited from locations far away from the customer and the suppliers. Problem troubleshooting and resolution from distant locations do not support the effective and quick response to changes in the information from the market [38] and could significantly hamper organisational growth. Subsequently, the ability to rapidly reconfigure the production process to meet both external (market, customer demands) and internal (production demands) is significantly hampered.

The relatively lower rating of Lean in the *Facility* characteristic of operation is also reflected in the low outcome of Lean on the *Supply Chain Positioning* characteristic of operation. The strategic position of the organisation along the supply chain plays an important role in meeting agreed customer commitments [39]. The goal of an integrated supply chain is to remove all boundaries to ease the flow of material, cash, resources and information. Although relative improvements have been recorded with regards to dealing with the stochastic nature inherent of MRO production in other business decision areas, limited application or success of Lean in the *Supply Chain* area could undo the progress that has been so far made. This will inevitably result in longer TAT which compromises one of the main objectives for Lean introduction in the first place.

A few organisations have addressed the application of Lean in the *Facility* and *Supply Chain Positioning* business decision areas. For example, business approaches like TotalCare by Rolls-Royce involved major restructuring of their business in order to effectively meet changing demands of the global aviation industry [40]. Not only has this restructuring generated commendable profits and new revenue streams, these organisations have been able to expedite prompt on-wing and shop assistance to customers globally and thus enhancing customer experience and satisfaction. By consolidating duplicated supply chains and aligning support network through intelligent data capture, they have managed to drive more efficient services to the customer [41]. Although it would take tremendous amount of effort to reach this stage in the Lean implementation programme, the benefits both in commercial and customer satisfaction terms are undeniable [40].

Analyses of the responses also provided a positive indication with regards to the application of Lean in the '*Capacity*' characteristic of operation. This area predominantly deals with the interaction between 'demand', 'supply' and 'utilisation of resources', and thus suggest that MRO organisations are finding relative success in the application of Lean tools and techniques to balance these three parameters. Although literature suggests that this balance is much easier to reach in conventional manufacturing context, it is more complex in MRO-type environments ([8], [9]). A requirement of MRO offering is the ability to meet unscheduled maintenance demand. These unscheduled demands could 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. The incorporation of these unscheduled demands into the production schedule will certainly affect the utilisation of resources which will also be reflected in the supply levels held by the organisation in most cases. The balancing of all these parameters within this characteristic of operation will affect the *Capacity* levels held by the organisation.

From the analyses of the responses, casual linkages could be drawn on the influence of Lean within the structural characteristics of operation. A stronger link was observed with the influence of Lean between the *Process and Technology* characteristics; *Planning and Control; Capacity* characteristics of operation. This relationship is based on the observation that the successful application of Lean in addressing physical resources and technologies that are used within operation, would invariable be reflected in the decisions made with regards to the flow of materials through the company and hence, the balance between these two areas of operation represented as capacity. A weaker causal link was also observed with the influence of Lean in the *Supply Chain Positioning* and the *Facility* characteristic of operation. This is because the position of the company with regards to its supply chain activities significantly determines the organisation's ability to expedite flexible and agile support to the customer especially on a global scale. Several permutations of these characteristics of operation would also reveal other relationships that exist between them. However, the most dominant of these relationships as observed from this empirical study are as it was observable from this empirical study are as briefly explained. These relationships can be expressed mathematically in terms of:

$$Lean\ influence\ (SCO): PT \propto PC \propto Cap$$

And

$$Lean\ influence\ (SCO): SCP \propto Fac$$

Where

SCO = Structural Characteristics of Operation

PT = Process and Technology

PC = Planning and Control

Cap = Capacity

SCP = Supply Chain Positioning

Fac = Facility

Although the casual linkages are inductive, they do reveal the approach of the MRO industry towards the adoption of Lean in aviation MRO context. The areas that seem to exhibit more positive emphasis are focused on the in-house production requirements of the organisation in terms of the shop-floor optimisation. However, the production requirement of the MRO industry extends beyond the interaction of these characteristics internally, but also as it relates with the external service provided to the customer especially with regards to its position on its supply chain activities in order to provide flexible and agile customer support. This has led the authors to conclude that:

Observation 1:

Although there has been a proliferation of Lean practices within structural characteristics of operation in the MRO industry, more emphasis has been placed on in-house areas that have direct interaction with the product.

4.1.2 Infra-structural characteristics:

The infra-structural characteristics of operation refer to the *relational* aspects of the MRO fabric that focuses on the interaction of the non-physical systems connected by similar value propositions as the production operations [8]. As already established by Karlsson and Ahlstrom [42], a company does not achieve Lean product development simply by implementing Lean techniques to the physical operations alone, instead, a successful move towards Lean requires approaching these interrelated systems in a coherent way. Successful Lean implementation will require addressing both the physical and the non-physical systems. Indeed, this is one of the core ideals of successful Lean implementation programmes.

The analysis of the response showed that the Lean has been most influential in the *'Human Resources'*, *'Quality Control'* and *'Performance Measurement'* strategic business decision areas. This suggests that along with the proliferation of Lean practices in some of the key structural characteristics of operation, Lean approaches have been adopted in the integration of the workers into the operation systems. In practice, literature suggests that this would involve: the division of labour; defined and controlled production systems; increased emphasis on worker skills, attitudes, motivation; improved quality of the product and service [42]. Consequentially, effective Lean programmes will also be characterised by accurate measuring metrics to evaluate the performance of various operating systems.

Apart from production cost savings, another major motivation for the application of Lean in the aviation MRO industry is turn-around-time reduction [44]. Although these motivations could improve the competitive advantage of the company, they are not reflective of the entire MRO capacity in that it they are more production focused. Thus, it can be said that the metrics that would be more popular in the aviation MRO industry would be more production orientated, such as labour utilisation, production cost and TAT. However, customisable metrics that account for the relational aspects of production will be few in number. If indeed the long-term success of Lean is dependent on the attitude and motivations of the people in the production system [4], the lack of appropriate metrics that account for the relational aspects suggest that the emphasis of Lean implementation has been focused on the tools and techniques which can be readily applied to product and not the Lean philosophy itself. The Lean philosophy, advocates a paradigm change in the way the whole operation system is run; both the transactional and the relational aspects [21]. Furthermore, literature suggests that a thorough understanding of the Lean philosophy itself has to be achieved across the whole business organisation in order to ensure the relevance, effectiveness and sustainability of its implementation ([7], [45]). Thus, focusing mainly on the tools and techniques alone can be counter-productive. This has led the authors to conclude that:

Observation 2:

Although there has been an increase in the adoption of Lean tools and techniques, the paradigm change advocated by Lean philosophy with regards to organisation-wide change is still lacking.

With *Quality* considered as a market qualifier and not an order-winning option in the aviation industry, it is a positive observation to note from the results that the implementation of Lean in the MRO industry has not compromised product quality. Womack et al. [21] suggests that most efficient production operations have introduced Lean principles where quality is focused on achieving product conformance and the minimisation of waste in materials and resource usage. However, with the 'Rework/Scrap cost' and 'Production Cost' not performing as well as other key performance areas (Figure 3), one can safely deduce that although the implementation of Lean in the MRO industry highlighted better product conformance, significant improvements are yet to be made on the minimisation of materials and resource wastes. This led to the observation that:

Observation 3:

Better product conformance is being achieved with the introduction of Lean with significant improvement yet to be made on the production and rework costs.

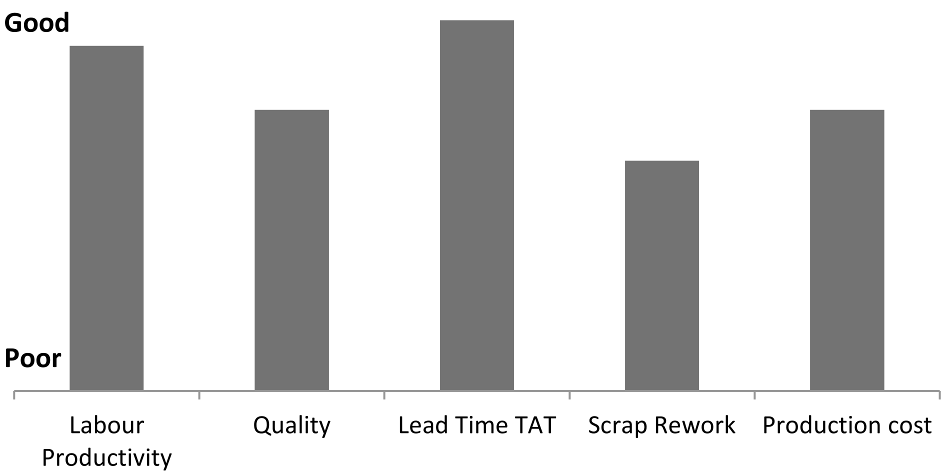

Figure 3: The outcome of Lean implementation within generic key performance measuring metrics

The analyses of the responses also indicate that Lean was least rated in areas such as '*New Product/Service Introduction*', '*Customer Relations'* and '*Supplier Relations'*. The relatively low product range of the aviation industry and its specialist nature may be the reason for Lean's relatively low performance with regards to the *New Product/Service introduction* strategic business decision area [1]. The low ratings in '*Customer Relations'* and '*Supplier Relations'* further supports previous observations that the Lean implementation has been focused more on the physical aspects of MRO operations that the non-physical (relational) aspects. Mathaisel [3] suggests that the reason for this is because it is easier to see waste on the shopfloor than anywhere else. This observation could also be indicative of the overall maturity of Lean programmes in the aviation MRO industry as only more advanced programmes within similar business environments have been able to apply Lean to all aspects of their operations system. The realisation of Lean across all aspects of the operation system is crucial especially in a product-centric service environment typical of the MRO industry because (and as earlier defined), it comprises of both the transactional (manufacture or production) and relational (service) type activities. The relative poor performance in the application of Lean to crucial aspects of the MRO operation system could either be a result of an incomplete perception of all its capacities of an inherent limitation to the application of Lean in this context. It could also be a result of paucity in the knowledge with regards to a strategic adoption of Lean across all aspects of the operation system. Whatever the case, it is clear that the MRO awareness of all its capacities both production and service orientated activities need to be clearly distinguished so as to allow for the coherent and strategic application of Lean.

Similar to the outcome in the structural characteristics of operation, casual linkages could also be drawn on the influence of Len within the infrastructural characteristics of operation. It was observed from the analysed results that an increase in the application of Lean within the *Performance Measurement* area would lead to a proportional to an increase in the *Quality* characteristic of operation and vice-versa. Invariable, the positive interaction between these two characteristics of operation would also lead to a positive outcome in the *Human Resources* characteristic of operation. This was the one of the major casual linkages that could be established as the relatively low outcome of Lean in other areas did not provide significant tangible relationships that could be observed from the responses. Mathematically, the observed casual linkage could be mathematically expressed as:

$$Lean\ influence\ (ISC): PM \propto Q \propto HR$$

Where;

ISC = Infra-structural Characteristics of Operation

PM =Performance measurement

Q = Quality

HR = Human Resources

Again, although this casual linkage is inductive, it does suggest that the Lean approaches have been employed extensively in performance measurements to ensure quality compliance is largely maintained. This has invariably contributed to the integration of employees into the operation system. However, this linkage does not provide the complete picture especially as it relates to a product-centric service industry. The relatively low outcome of the application of Lean in the *Customer a*nd *Supplier Relations* which are both critical elements of a product-centric service environment, support earlier observations that the focus of Lean application in the MRO industry has been largely directed towards the production aspects of the industry than its service counterparts. Thus, although successes alluded to the application of Lean will be visible in the short-term; its long term sustenance across the entire operation system in fulfilling all its demands could be significantly hampered. This has led the authors to conclude that:

Observation 4:

Although the current trend reveals that more Lean emphasis is been placed on the production-orientated activities, Lean success in the MRO industry can only be sustained when it is applied across all aspects of its operation system.

4.2 Extent of Lean adoption within other contextual factors

With a few authors on Lean ([31], [33], [34]) suggesting that Lean programmes are plant specific, it was also necessary to identify the operation footprint of the responding organisation and deduce the relationship that exists between their operation footprint and their approach to Lean itself. A generic list of typical MRO activities common to all sectors within the industry were identified as listed Table 2 within which the operation footprint of the respondents will be profiled.

Analyses of the responses showed that majority of the responding organisations were more active in their production-orientated activities than they were in their service-orientated activities. Although authors like Chandler [46] and Child [47] suggests that the effective integration of service orientated activities within an organisation may be complicated, more recent publications perceive the integration of services into the operations footprint as a competitive necessity ([8], [48], [49]). This suggests that the position that many MRO organisations take with regards to their operation footprint is more skewed towards the production aspects than it is towards their service orientated operations. Thus, it was no surprise to observe from the responses that the Lean practices and tools that were adopted were significantly biased towards their production orientated activities.

Conversely, it can be observed that larger organisations, irrespective of their position on their production and service footprints, were more receptive overall to the adoption of Lean practices. This was evidenced in the number of Lean practices they had adopted. Shah and Ward [31] suggest that the reason larger organisations are more receptive to the that adoption of Lean practices is because they possess both capital and human resources that facilitate adoption and implementation of Lean practices as well as returns on investments associated with Lean adoption [50]. However, failure to realise the importance and benefits of Lean adoption across all aspects of operation (production and service), could serve as an impediment to its successful implementation [31]. Although the responses showed very positive indication of Lean adoption within the aviation MRO industry, the current position taken by the industry on its service and production activities have prompted the authors to conclude that:

Observation 5:

MRO organisations with larger production footprints are more receptive to the adoption of Lean tools and techniques.

PRODUCTION ORIENTATED OPERATIONS	DISASSEMBLY
	STRIPPING/REMOVAL OF SURFACE FINISHES
	MEASUREMENT
	INSPECTION
	MACHINING
	PLATING
	NON-DESTRUCTIVE
	TESTING
	PART-PEENING
	SPECIAL COATING
	ASSEMBLY
	PAINT
	STRESS RELIEVING/DE-EMBRITTLEMENT
	BAKE MANUFACTURE
	RE-WIRING
	TEST (E.G. FLIGHT, ELECTRIC)
SERVICE ORIENTATED OPERATIONS	INSTALLATION OF PRODUCT
	PRODUCT TRAINING
	CUSTOMER HELPDESK (SUPPORT)
	BREAKDOWN REPAIR
	SPARE PARTS SALES
	PREVENTIVE MAINTENANCE
	DIAGNOSTICS
	PRODUCT DISPOSAL
	PROVISION OF LABOUR
	SYSTEM INTEGRATION FINANCING
	ADVICE/CONSULTING
	NON-AEROSPACE

Table 2: Generic MRO operations

4.3 Lean influence on MRO output

Analyses of the responses indicate that the Lean practices that have been adopted most include Just-in-time (JIT), 5S and Takt time. Other practices such as Continuous improvement and Six Sigma were also being adopted within MRO. Evaluation of the practices that have been adopted most within the MRO industry present mixed evidence towards the alluded success. For example, although effective JIT implementation is associated with inventory reduction ([51], [52], [53]), there is evidence that this is not always the case. Analyses of the results also show that labour productivity has seen the most improvement which could infer a reduction in work-in-progress (WIP). Boute et al., [54] made a similar proposition that the effect of JIT implementation is mostly realised in WIP reduction and raw material inventory ratio as opposed to a direct reduction in inventory ratio. This reduction in WIP would also contribute to the reduction in overall TAT.

Furthermore, 5S is referred to as the foundation upon which all other Lean business improvement initiatives are established on. This is because the ‘5S’ process is a simple methodical team based approach to organizing work space to ensure that it is tidy, arranged ergonomically, efficient and capable of repeatable, quality output. Successful 5S implementation contributes to significant reductions in the 7 wastes identified by Ohno [55] as unnecessary clutter is removed from the working environment and tools and equipment necessary to carry-out tasks are located in the most ergonomic locations. Effective 5S implementation also makes all malfunctions in the production process more obvious so that corrective actions are prompt. Other tools such as continuous improvement initiatives and Six Sigma would also result in similar benefits in particularly in the output parameters examined in Figure 3. Since the benefits indicated by the organisations are consistent with the prevalent tools implemented, the authors are led to conclude that:

Observation 6:

Lean success in MRO output is confirmed and consistent with literature despite being a product-centric service environment.

5 SUMMARY AND CONCLUSIONS

MRO framework is made up of both production-orientated and service-orientated functions [6]. These functions can be described in conventional manufacturing and service terms. Although neither description of the industry is incorrect, they are independently incomplete descriptions of the MRO industry. This is because the MRO industry has elements akin to the traditional manufacturing environments and traditional service environments. As such, literature review refers to the MRO industry as a product-centric service industry. Thus, the extent of Lean adoption within the MRO industry has to be established within the scope of these two aspects.

The survey set out to find out the extent of Lean adoption within the aviation MRO industry by considering its influence within identified key characteristics of operation also referred to as the key business decision areas. This interest is based on the preposition that successful implementation of Lean will be translated and filtered across all these key areas, both structural and infrastructural.

Analysis of the responses within the key structural characteristics of operation showed that the strategic decision areas that have been most influenced by Lean are *‘Process & Technology’* and *‘Planning and Control’*. This suggests that Lean tools are being employed in enhancing both the production process that the planning systems responsible for production. Conversely, the responses indicate Lean to have the lesser impacts in the *'Facility'* and *'Supply Chain'* structural characteristics of operation. With the '*Facility'* decision area representing the proximity of the organisation to customers, suppliers and markets and the '*Supply Chain'* area representing the position of the organisation within the MRO production footprint; it can be observed that the MRO industry had not sufficiently employed Lean approaches in dealing with agile and quick customer requirements.

Similarly, analysis of the results indicate that more emphasis on Lean tools have been placed within the '*Human Resources'*, '*Quality Control'* and '*Performance Measurement'* key infrastructural characteristics of operation. Lean is associated with the effective integration of people into their production systems through the division of labour and defined and controlled production systems [43]. The responses from this section suggest that emphasis has been placed on worker skills, their attitudes and motivation whilst ensuring that product quality is maintained. The results indicate that emphasis have been placed on the measuring metrics employed in evaluating the performance of various organisations. Although this survey did not explore what exact measuring metrics have been employed and their appropriateness, it will be safe to suggest that the adopted metrics would be relatively limited to measuring production outputs such as labour utilisation, production cost and TAT savings with relatively lower focus on their service orientated functions where appropriate customisable metrics would have to be developed.

Conversely, it was noted from the response that Lean was least rated in areas such as '*New Product/Service Introduction'*, *'Customer Relations'* and *'Supplier Relations'*. The relatively low product range of the aviation industry and its specialist nature may be the reason for Lean's relatively poor performance in the *New Product/Service Introduction*. However, the lower ratings in the relational aspects such as *'Customer Relations'* and *'Supplier Relations'* supports the overwhelming finding that the focus of Lean has mainly directed toward production-orientated functions where Mathaisel [3] suggests, is more easy to see waste. The application of Lean to the service-orientated functions is notably lacking.

Often the primary goal of Lean implementation has been to increase outcomes like productivity, reduce lead times and costs, improve quality in a manufacturing shop, factory or company [56]. However, the uniqueness of the MRO environment requires that Lean implementation is not limited to purely production activities but to also include service-orientated activities. Although Lean tools and techniques are varied such that some of them exclusively affect the production department, there are other initiatives that integrate several company functions. The overwhelming conclusion of this survey is that although Lean has been successfully implemented in the aviation MRO industry, its implementation has been limited to the production shop-floor activities where waste is more easily noticed with little attention paid to the service-related operation of the industry. Although Zayco et al. [57] and Ahlström [58] advocate for the gradual implementation of the elements of Lean, the overall success of MRO Lean programmes can only be accurately measured when an integrated approach addressing both the production and service aspects of the business is adopted.

Furthermore, analysis reveals all the respondents indicated large footprint with regards to their production functions with only a few organisations indicating a similar size footprint on their service operations. Although Pettersen [33] suggest that Lean programmes are plant specific, it was observable from the response that organisations with relatively larger production footprint were more receptive to the adoption of Lean as evidenced by the number of tools adopted. However, it was no surprise to observe that majority of the tools that were adopted are directly linked to their production-orientated activities than the service-orientated activities. This finding could either be a result of a deliberate phased implementation of Lean to first address the production related concerns and then the service related concerns or it could be the a result of the lack of a coherent and holistic approach of Lean implementation within a product-centric service environment. Notwithstanding, casual linkages between the size of the production footprint and the motivation for the adoption of Lean could still be drawn. Similar to manufacturing environments, it was also observed from the responses that organisations with larger production footprints seemed to be more receptive to the adoption of Lean. Conversely, analyses of the response reveal that significant improvements were recorded in all outputs of production. Most notable of them was in Labour Productivity, Quality and Production Cost. Although the actual percentage improvements were not recorded, this finding further validates the success attributed to Lean by many organisations.

This research provides evidence to the successful adoption of Lean in the aviation MRO industry albeit limited to the production-orientated operations with less attention provided to the service orientated operations. However, without wanting to undermine the value of this study, it should be noted that the findings from this survey should be treated as indicative. Based on the outcome of this empirical study, the authors of this paper recommend further research into an integrated approach of Lean implementation that concurrently considers its adoption across both the production-orientated functions and its service-orientated activities. This will involve working closely with interested partners to develop and establish best practices across all the key characteristics of operations and the relations between them. The results will be collated to form a conceptual framework of the 'Ideal Lean MRO'. The authors look forward to reporting this work in the near future.

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7 APPENDIX

Please, either attach your business card or complete the following information.

Name:
Company:
Position:
Job description:
Plant/Building/Department:
Address:
Phone:
Email:

Section 1:

WHAT MRO SECTOR DOES YOUR COMPANY BELONG TO?
(PLEASE TICK THE OPTION(S) THAT APPLY)

- *Heavy Maintenance Visit* [YES] [NO]
- *Engine Overhaul* [YES] [NO]
- *Component Overhaul* [YES] [NO]
- *Line Maintenance* [YES] [NO]
- *Avionics* [YES] [NO]
- *Modifications and Retro-fits* [YES] [NO]

OTHER (PLEASE SPECIFY)...

PLEASE INDICATE WHICH OF THE FOLLOWING OPERATIONS ARE INTERNALLY CARRIED OUT IN YOUR COMPANY?

(PLEASE TICK THE OPTION(S) THAT APPLIES)

- DISASSEMBLY - [YES] [NO]
- STRIPPING/REMOVAL OF SURFACE FINISHES - [YES] [NO]
- MEASUREMENT - [YES] [NO]
- INSPECTION - [YES] [NO]
- MACHINING - [YES] [NO]
- PLATING - [YES] [NO]
- NON-DESTRUCTIVE TESTING - [YES] [NO]
- PART-PEENING - [YES] [NO]
- SPECIAL COATING - [YES] [NO]
- ASSEMBLY - [YES] [NO]
- PAINT - [YES] [NO]
- STRESS RELIEVING/DE-EMBRITTLEMENT BAKE - [YES] [NO]
- MANUFACTURE - [YES] [NO]
- RE-WIRING - [YES] [NO]
- TEST (E.G. FLIGHT, ELECTRIC) - [YES] [NO]

WHAT EXTERNAL SERVICES DO YOU OFFER YOUR CUSTOMER(S)?

(PLEASE TICK THE OPTION(S) THAT APPLIES)

- INSTALLATION OF PRODUCT [YES] [NO]
- PRODUCT TRAINING [YES] [NO]
- CUSTOMER HELPDESK (SUPPORT) [YES] [NO]
- BREAKDOWN REPAIR [YES] [NO]
- SPARE PARTS SALES [YES] [NO]
- PREVENTIVE MAINTENANCE [YES] [NO]
- DIAGNOSTICS [YES] [NO]
- PRODUCT DISPOSAL [YES] [NO]
- PROVISION OF LABOUR [YES] [NO]
- SYSTEM INTEGRATION [YES] [NO]
- FINANCING [YES] [NO]
- ADVICE/CONSULTING [YES] [NO]
- NON AEROSPACE [YES] [NO]

OTHER (PLEASE SPECIFY)..

WHICH OF THE FOLLOWING (ACTIVITIES) HAS BEEN IMPLEMENTED IN YOUR COMPANY?
(PLEASE TICK THE OPTION(S) THAT APPLIES)

SIX SIGMA [YES] [NO]
CONTINUOUS IMPROVEMENTS [YES] [NO]
LEAN MANUFACTURING/MAINTENANCE [YES] [NO]
AGILE MANUFACTURING/MAINTENANCE [YES] [NO]
KAIZEN [YES] [NO]
JUST-IN-TIME MANUFACTURE/MAINTENANCE [YES] [NO]
BUNDLED ASSET MANAGEMENT PROGRAMMES [YES] [NO]
5S [YES] [NO]
TPM [YES] [NO]
OVERALL EQUIPMENT EFFECTIVENESS [YES] [NO]
MAPPING (PROCESS, VALUE, LEAD) [YES] [NO]
INVENTORY MANAGEMENT [YES] [NO]
VISUAL MANAGEMENT [YES] [NO]
ROOT CAUSE PROBLEM SOLVING [YES] [NO]
POKAYOKE [YES] [NO]
SELF AUDITS [YES] [NO]
STORYBOARDING [YES] [NO]
KANBAN [YES] [NO]
TAKT TIME [YES] [NO]
VALUE FOCUSED THINKING [YES] [NO]
SUPPLIER CONSOLIDATION/ASSOCIATIONS [YES] [NO]
OPEN BOOK MANAGEMENT [YES] [NO]

OTHER (PLEASE SPECIFY)...

PLEASE INDICATE WHERE, IN YOUR OPINION, THE MOST BENEFITS HAVE BEEN SEEN AS A RESULT OF IMPLEMENTING THE ABOVE TOOLS?

(PLEASE GRADE THEM IN ORDER OF IMPORTANCE. NOTE: 1 – MOST BENEFICIAL; 3 LEAST BENEFICIAL)

	(LEAN) BENEFITS
LABOUR PRODUCTIVITY	[1] [2] [3]
QUALITY	[1] [2] [3]
LEAD TIME / TURN-AROUND-TIME (TAT) REDUCTION	[1] [2] [3]
SCRAP AND REWORK COST	[1] [2] [3]
PRODUCTION COST	[1] [2] [3]

Section 2:

OPERATIONAL SYSTEMS ARE GENERALLY CLASSIFIED INTO THE FOLLOWING CHARACTERISTICS. PLEASE INDICATE HOW SUCCESSFUL (LEAN) TOOLS AND TECHNIQUES HAS BEEN IN THESE AREAS.
(PLEASE TICK THE OPTION(S) THAT APPLIES. NOTE: 1 – LEAST SUCCESSFUL; 5 – MOST SUCCESSFUL)

	OPERATIONAL CHARACTERISTIC	**SUCCESS RATING**
STRUCTURAL	**PROCESS AND TECHNOLOGY** Increased emphasis on automated systems/varying range of technology, information systems and databases to enhance product conformance, efficiency, communication and customer interaction. Emphasis on **production (shop-floor layout), processes** e.g. machine centres.	**[1] [2] [3] [4] [5]**
	CAPACITY Increased emphasis on the interaction between **Human Resources**, **Technology** and **Supply Chain** to match demand.	**[1] [2] [3] [4] [5]**
	FACILITIES Increased emphasis on **business proximity to market/customer**. Re-organisation of business into network of smaller business units. Possible 'showcase' of the facility.	**[1] [2] [3] [4] [5]**
	SUPPLY CHAIN POSITIONING Increased emphasis over the range of activities to be carried out by the company i.e. outsourcing, in-sourcing, subcontracts, Make vs Buy etc. Emphasis on the span of process (vertical integration).	**[1] [2] [3] [4] [5]**
	PLANNING AND CONTROL Increased emphasis on the flow of materials in and through the company e.g. Enterprise Resource Planning (ERP), Materials Requirements Planning (MRP) 2, Optimised Production Technology (OPT), Period Batch Control (OPC), Kanban ConWip, Batching, Jobbing, Flow etc. Increased emphasis on the optimisation of product availability and interaction between **information capacity** and **stock**.	**[1] [2] [3] [4] [5]**

INFRASTRUCTURAL	**HUMAN RESOURCES** Increased emphasis on worker skills, defined routines, training, motivation, attitudes, values and culture of the organisation.	**[1] [2] [3] [4] [5]**
	QUALITY CONTROL Increased emphasis on quality conformance (to reduce scrap), product assurance and customer satisfaction. E.g. ISO 9000/1, ISO 1401, Statistical Process Control (SPC), Statistical Quality Control (SQC) etc.	**[1] [2] [3] [4] [5]**
	NEW PRODUCT / SERVICE INTRODUCTION Increased emphasis on the product range(s) and/or supporting services.	**[1] [2] [3] [4] [5]**
	PERFORMANCE MEASUREMENT Increased emphasis and/or change in performance measuring methods e.g. from piece-work to cell based incentives. Internal measures such as Machine utilisation, worker utilisation, WIP, Door-Door time etc	**[1] [2] [3] [4] [5]**
	SUPPLIER RELATIONS Increased emphasis and change in the sourcing of resources/materials e.g. from single sourcing to multi sourcing. Integration of external and internal supply chains. Increased emphasis on responsiveness of supply chain.	**[1] [2] [3] [4] [5]**
	CUSTOMER RELATIONS Increased emphasis on customer interaction and feedback.	**[1] [2] [3] [4] [5]**

WITH REGARDS TO YOUR BUSINESS OPERATIONS, PLEASE INDICATE THE OPERATIONAL CHARACTERISTIC YOU ARE MOST PROUD OF.

(PLEASE TICK THE OPTION(S) THAT APPLIES. NOTE: 1 – LEAST PROUD OF; 3- MOST PROUD OF)

PROCESS AND TECHNOLOGY	[1] [2] [3]
CAPACITY	[1] [2] [3]
FACILITIES	[1] [2] [3]
SUPPLY CHAIN POSITIONING	[1] [2] [3]
PLANNING AND CONTROL	[1] [2] [3]
HUMAN RESOURCES	[1] [2] [3]
QUALITY CONTROL	[1] [2] [3]
PRODUCT / SERVICE RANGE	[1] [2] [3]
NEW PRODUCT / SERVICE INTRODUCTION	[1] [2] [3]
PERFORMANCE MEASUREMENT	[1] [2] [3]
SUPPLIER RELATIONS	[1] [2] [3]
CUSTOMER RELATIONS	[1] [2] [3]

OTHER (PLEASE SPECIFY)..

PLEASE INCLUDE ANY OTHER COMMENTS IN THIS BOX.

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2016-02-01

Towards the strategic adoption of Lean in aviation Maintenance Repair and Overhaul (MRO) industry: an empirical þÿstudy into the industry s Lean

Ayeni, Peter

Emerald

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