LEAN-SAFE OPERATIONS FOR THE AVIATION INDUSTRY

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ABSTRACT
The aviation industry continues to face significant competitive and cost reduction pressures while simultaneously striving to make the industry even safer than it currently is. Consequently, the industry is struggling to solve a very practical problem – how to achieve the required operational efficiency improvements without compromising safety. This paper argues that the integration of safety, and in particular, human factors, with lean operations represents a potential solution to this dilemma, i.e. lean-safe operations. This paper begins by highlighting the rationale for such integration. It then proposes a Lean-Safe Aviation Enterprise Model, incorporating lean-safe principles and practices. In addition, the paper focuses on some key lean tools that can be used to achieve both efficiency and safety goals. The paper concludes by highlighting the implications of lean-safe operations both for the aviation industry and for other safety-critical industries.

Keywords: aviation industry, lean-safe operations, human factors

INTRODUCTION

The aviation industry is facing significant challenges for the future with continuously increasing competition, cost reduction pressures and skills shortages. In addition, given growing air traffic volumes, there is a relentless drive to make an already safe industry even safer. Furthermore, the drive to make aviation more environmentally-friendly is rapidly gathering momentum. Therefore, the industry is under pressure to improve productivity, enhance safety and ensure sustainability, i.e. a lean-safe-green agenda has emerged. This holds true for all sectors of the industry, including aerospace manufacturing, air transport and maintenance, repair and overhaul (MRO). This paper focuses on the first dimension of this agenda – the lean-safe dimension.

Due to the increasing technical reliability of aircraft and their systems, the majority of safety improvements are expected to primarily emerge from better management of the human elements of the aviation system. Therefore, the discipline of human factors, a key component of safety science, is gaining prominence. In June 2005, the European Commission established a large Integrated Project aimed at transforming the aviation industry and improving flight safety through the integration of human factors knowledge into all aviation-related activities. This project is known as HILAS: Human Integration in the Life-cycle of Aviation Systems. The HILAS network is

comprised of 40 aviation stakeholders including aerospace manufacturers and suppliers, airline operators, maintenance organizations, universities and research institutes, human factors specialist organizations and information technology (IT) consultants. The network composition is illustrated in Figure 1 below:

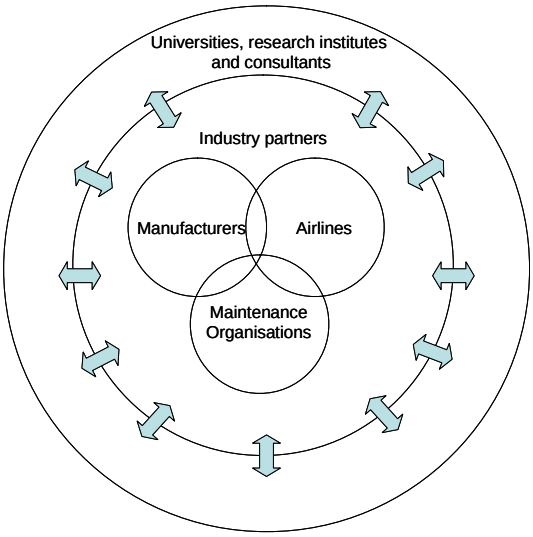


Figure 1 – Composition of the HILAS Network

One of the research imperatives within the HILAS project involves the cost-effective integration of human factors within airline and maintenance operations in order to improve overall safety and efficiency at the industry level. This paper proposes a lean-safe operations management approach to address the practical problems of the industry. The paper begins by highlighting the rationale for lean-safe operations. It then proposes a Lean-Safe Aviation Enterprise Model, incorporating lean-safe principles and practices. In addition, the paper focuses on some key lean tools that can be used to achieve both efficiency and safety goals. The paper concludes by highlighting the implications of lean-safe operations both for the aviation industry and for other safety-critical industries.

RESEARCH METHODOLOGY

The research question being addressed in this paper has been derived from a specific challenge facing the aviation industry and, in particular, those airlines and maintenance organisations within the HILAS consortium – how can aviation organisations respond to competitive and cost reduction pressures without compromising safety? Given the fact that lean operations has been widely implemented in the aerospace manufacturing environment and that the current aviation safety priority is human factors, the integration of these two previously independent disciplines was proposed as a practical solution to this industry problem (Ward, 2006). This pragmatic, problem-focused approach is accepted as a valid methodology for management research (Aram and Salipante, 2003).

If it is accepted that it is worth investigating the potential integration of lean operations and human factors, it is then necessary to determine how best to achieve this integration. This involved an extensive literature survey to: (1) examine lean operations and its application in the aerospace and aviation sectors to date, and (2) explore the evolution of human factors within the aviation safety context. This facilitated the identification and comparison of the principles, practices and tools used within both the lean operations and human factors fields. Consequently, it enabled the

determination of how best they might be integrated to ensure maximum benefits to aviation organisations.

RATIONALE FOR LEAN-SAFE OPERATIONS

The aerospace manufacturing sector has responded to on-going competitive and cost reduction pressures through the widespread implementation of lean principles and practices since the early 1990's (Womack and Jones, 1996; AW&ST, 1999; Murman et al, 2002; Ward, 2003). However, there are only isolated examples of lean being applied in airline and maintenance environments (Hardgrave, 2006; Moorman, 2005; Warwick, 2007). The reason for this may lie in the fact that there is a critical difference between the operating contexts of manufacturing organisations and that of airlines or maintenance organisations. While safety is paramount for all aviation stakeholders, resulting in a highly-regulated industry, it is implicit at the manufacturing stage because it has been taken into consideration during the design stage. Therefore, the focus during manufacturing is on quality and conformance to design rather than safety *per se*. Consequently, lean manufacturing has prioritised cost, quality and delivery. However, for organisations operating within the in-service phase of the life-cycle, safety needs to be more explicit. Within airlines and maintenance organisations, operational improvement initiatives cannot be seen to adversely affect safety. With the advent of low-cost airlines, ruthless cost-cutting is often perceived as a safety risk (Flight International, 2006). However, all airlines and their supply chains are now seeking to improve their operating efficiency, enhance their processes and reduce costs. The fundamental challenge for the industry, therefore, is how to achieve operational effectiveness without compromising safety (UK CAA, 2002; Ward, 2006).

Due to the increasing technical reliability of aircraft systems, the UK Civil Aviation Authority (UK CAA) argues that "*the expansion of human factors awareness presents the international aviation community with the single most significant opportunity to make aviation both safer and more efficient*" (UK CAA, 2002, pvii). However, to date, human factors programmes have often been "*marginalised and regarded as a temporary fashion*" (UK CAA, 2003, Ch2, p4). Therefore, it is believed that human factors initiatives are more effective if they are integrated within existing company processes such as quality management and continuous improvement programmes (UK-HFCAG, 1999; UK CAA, 2003).

Table 1: Evolution of Lean-Safe Operations Management

<table>
<tr><th colspan="2">Phase 1(1980's/ 1990's): Separation of Human Factors from Operational Improvement</th></tr>
<tr><td>Lean Operations/ Process Improvement
Increased emphasis on process and systems thinking for operations management
Focus on cost reduction, quality improvement, waste elimination, cycle time and lead time reduction
Identification of value-added, non-value-added and wasteful activities from the customer's perspective
No explicit focus on safety/ human factors although implicit in many lean tools and techniques
Primarily applied in aerospace manufacturing</td><td>Human Factors
Human factors research conducted and expertise developed
Human factors specialists employed within aviation organisations
Human factors often marginalized within aviation organisations
No explicit link to operational improvement, quality or organizational change initiatives
Primarily applied in Flight Deck and Flight Operations; more recently in Aircraft Maintenance and Air Traffic Control</td></tr>
<tr><th colspan="2">Phase 2 (Current Focus): Integrated Human Factors and Operations Management</th></tr>
<tr><td colspan="2">Recognition that human factors needs to be integrated with other management and information systems to be more effective
Emphasis on aligning human factors with existing change/ process improvement initiatives, information systems and management approaches
Focus on developing human factors awareness in all aviation organizations and at industry level</td></tr>
</table>

Phase 3 (Future Vision): Lean-Safe Operations Management
▪ A radical transformation of management and information systems to seamlessly and simultaneously achieve safety (human factors) and operational goals ▪ The use of human factors knowledge to identify strategic opportunities, stimulate innovation and create competitive advantage ▪ Human factors is inherent in all roles and processes across the aviation life-cycle

Ward (2006) presents a framework for the transition of the aviation industry towards a lean-safe operations management approach, which integrates lean operations and human factors. This is shown in Table 1 above. Essentially, this framework highlights the potential for combining lean with human factors initiatives and how this could potentially evolve over time. However, once the possibility and desirability of integrating lean operations and human factors is understood, it is necessary to clarify in more detail the principles that should underpin a transition to lean-safe operations management, the practices that should be employed by companies that wish to move in this direction and the specific tools that can support its implementation. The following sections address these issues.

A LEAN-SAFE AVIATION ENTERPRISE MODEL

The US Lean Aerospace Initiative (US LAI) was launched in 1991 to transfer lean principles and practices developed in the automotive sector to the US aerospace and defence industry. The US LAI continues to this day and operates as a consortium of key aerospace stakeholders including industry, government and academia, co-ordinated by the Massachusetts Institute of Technology (MIT). Empirical studies undertaken within the US LAI resulted in the development of the Lean Enterprise Model (LEM). This model consolidated and codified the lean principles and practices that would ideally be embodied within a lean aerospace enterprise (MIT, 1996; Murman et al, 2002). Consequently, the model represents a valuable starting point from which to begin to integrate aviation human factors and safety principles and practices with lean principles and practices at an enterprise level. This section illustrates how the LEM can be adapted to make safety and human factors principles and practices more explicit.

The Lean Enterprise Model (LEM)

A simplified version of the LEM is shown in Table 2 below (the complete version can be found at http://lean.mit.edu). The model is comprised of both lean principles and lean practices, with the practices being evenly split between human-oriented practices and process-oriented practices.

Table 2: Simplified Lean Enterprise Model

Principles	
Waste minimisation/ value creation Responsiveness to change Right thing at the right place, at the right time, and in the right quantity Effective relationships within the value stream Continuous improvement Quality from the beginning	
Practices	
Human-oriented Practices	***Process-oriented Practices***
Lean leadership/ employee involvement	Seamless information flow
Relationships of trust within the extended enterprise	Integrated life-cycle and systems approach to product and process development
Decision-making at the lowest appropriate level/ employee empowerment	Process capability and control
Skill, competence and knowledge development	Continuous improvement culture supported by quantitative measurement and analysis
Customer and stakeholder focus	Optimised flow of products and services

Learning environment	Agility and demand levelling

Source: Adapted from the US LAI Lean Enterprise Model, (1996) http://lean.mit.edu; Murman et al, (2002)

An examination of the LEM principles and practices reveals that it supports many of the concepts underpinning aviation human factors and safety management. The fact that the LEM practices have been categorised by Murman et al (2002) into human-oriented and process-oriented practices is an immediate indicator of common thinking because the HILAS consortium is embracing a socio-technical systems view of aviation human factors. However, the LEM was not developed with a specific and explicit focus on human factors and safety in mind. Therefore, for the model to be adapted for use in airlines and aviation maintenance organisations, a more detailed examination of aviation human factors and safety management principles and practices is required.

Aviation Human Factors and Safety Management Principles and Practices

Although there has been a lot of research activity in the aviation human factors and safety fields over many years, the associated principles and practices have not been consolidated in the way that lean principles and practices have been brought together in the LEM. However, a wide survey of the relevant literature reveals the key themes.

Aviation human factors is primarily concerned with reducing the likelihood of an aircraft accident by maximising human performance and minimising the opportunity for human error to occur throughout the aviation system. It is accepted that human error cannot be eliminated. However, systems can be established to minimise error and to minimise the consequences of errors that do occur. Human factors is concerned with individual psychology and physiology, team dynamics, the interaction of people with technical systems and work environments, as well as the impact of organisational factors on human performance. Human factors is now taking a socio-technical systems and life-cycle perspective and forms part of the broader aviation safety agenda. This systems view is underpinned by a just culture which accepts that human error is a system problem. Practices associated with human factors and safety management include:

- The design of safe and efficient work practices
- The design of rules, regulations, procedures, documentation and manuals that minimise human error
- The design of flight decks, aircraft cabins, controls and displays etc to optimise human-machine/ human-computer interaction
- The analysis of past accidents and incidents in order to improve, change, learn and reduce risk
- The continuous monitoring of incidents to strengthen system defences
- The implementation of safety management systems.

A Lean-Safe Aviation Enterprise Model (LeSAM)

The original LEM can be adapted relatively easily so that it can be more applicable within airline and maintenance environments. A Lean-Safe Aviation Enterprise Model (LeSAM) can be generated by explicitly integrating aviation human factors and safety management principles and practices into the model. With regard to lean principles, these can be extended to lean-safe principles by emphasising human factors, safety and risk-related dimensions. This is shown in Table 3 below.

Table 3:Extending Lean Principles to Lean-Safe Principles

Lean Principles	**Lean-safe Principles**
Waste minimisation/ value creation	Waste ***and error*** minimisation/ value creation
Responsiveness to change	***Accident and incident prevention and reduction***
Right thing at the right place, at the right time, and in the right quantity	Responsiveness to change ***and risks***
Effective relationships within the value stream	Right thing at the right place, at the right time, and in the right quantity
Continuous improvement	Effective relationships within the value stream

Quality from the beginning	Continuous ***productivity and safety*** improvement Quality ***and safety*** from the beginning

An equivalent exercise has been undertaken with regard to lean practices. This is too detailed to present here. However, similarities that have emerged from a detailed examination of the LEM and aviation human factors and safety management practices include:

- An enterprise-level and life-cycle focus
- An emphasis on trust, teamwork and relationships
- The importance of data-driven management, information flow, root cause analysis and performance measurement
- The highlighting of skills, knowledge, learning from experience and training
- A focus on risk management.

LEAN-SAFE TOOLS

The Lean-Safe Aviation Enterprise Model (LeSAM) provides a framework to guide the direction of an integrated lean, safety and human factors programme within an organisation. However, this model needs to be supplemented by tools which provide the mechanism to implement lean-safe principles and practices appropriately and successfully.

As the lean concept has evolved, many lean tools have been developed in order to support lean implementation within a range of environments including manufacturing and service operations. These tools have been consolidated in lean toolboxes, such as those published by Bicheno (2004) and Quest Worldwide (2006). All of the lean tools have been examined to identify how these tools can be used to address human factors issues, thereby having the potential to improve safety. This section presents a selection of well-known lean tools and demonstrates where the most obvious synergies lie.

5S (Housekeeping/ Workplace Organisation)

5S is a fundamental lean tool and often one that is applied at the very early stages of a lean implementation. It provides the foundation for undertaking further lean activities. 5S is derived from five Japanese words beginning with 'S' which have been translated into five English words beginning with 'S'. These are explained in Table 1 below.

Table 1: Explanation of 5S's

Japanese	***English***	***Explanation***
Seiri	Sort	Identify unnecessary items and remove them (parts, equipment, documentation etc)
Seiton	Straighten	Arrange items close to where they are needed (the most commonly used files/ tools etc). Set limits to the amount stored and clearly mark all locations.
Seiso	Shine	Cleanliness is a form of inspection. Eliminate rubbish, dirt, dust and scrap. Ensure tools, equipment and workplace shine. Seek potential problems before they impact and tackle the source of contamination. Establish a cleaning routine at the end of work shifts.
Seiketsu	Standardise	Establish standards – for cleanliness, frequency, responsibilities, when things are to be done, what equipment to use. 5S is also a basic foundation for standard work.
Shitsuke	Strengthen	Work to the standards. Train everyone. Regularly review. Undertake audits, use visual displays and controls. Make the first 4S's strong in habit.

Source: Quest International, 2006

Lean organisations often conduct “red tagging” exercises to identify items which should be removed from the work area. All remaining items are then given a permanent home – in cupboards, on shelves, in containers, on shadow boards, for example. They are then clearly labelled or colour coded so that items can be easily found or that it is immediately obvious if they are missing. This very simple tool improves the working environment, increases quality, supports visual management and facilitates teamwork.

However, this lean tool also has the potential to improve flight safety by minimising the chances of human error occurring. Take aircraft maintenance as an example. Using the wrong tools and equipment, not having access to the right tools and equipment or leaving tools in the aircraft after a maintenance procedure has been carried out have been identified as significant contributors to maintenance-related aircraft accidents and incidents (JAA, 2001; Reason and Hobbs, 2003). Other contributing factors include ineffective communication, poor shift and/ or task handovers and deviations from procedures.

The implementation of 5S in an aircraft maintenance organisation can ensure that the appropriate tools, equipment and documentation are available at the work station at all times. In addition, any items which are not required are removed, reducing the possibility for error. Furthermore, 5S can improve communication and shift/ task handovers because employees can easily see where all items should be and quickly identify if there is anything missing. 5S may also discourage employees from deviating from procedures by making it easier to carry out tasks with the right tools, equipment and documentation.

Value Stream Mapping

Value Stream Mapping is a tool for understanding how materials and information flows through an organisation to deliver value to a customer (Rother and Shook, 2003). Value Stream Mapping can be undertaken at the level of the extended enterprise (tracking all of the individual companies that a product travels through prior to reaching the final customer), the level of an individual enterprise (from goods inwards to delivery to the next customer in the value stream) and at the level of a particular division within one enterprise (from arrival in the division to delivery to the next internal customer). The main aim of Value Stream Mapping is to reveal the time a product or service actually takes to go through all the processes it requires and identify all of the non-value-added or wasteful activities within the existing value stream. Consequently, the priorities for waste elimination, improvement initiatives and organisational change can be agreed.

Within the human factors domain, a tool called task analysis is used to identify and examine the tasks that must be performed by users when they interact with systems (Kirwan and Ainsworth, 1992). The main aim of task analysis is to ensure that specific tasks can be completed without error. This tool is similar in concept to Value Stream Mapping or process mapping but it is done at a much more detailed level. However, the discipline of human factors is now beginning to view tasks within the process and the wider organisational context in which they take place (Vincente, 2004; Reason and Hobbs, 2003). In addition, Value Stream Mapping is similar to the human factors concept of an error chain, where accidents are usually found to have been caused by a sequence of errors over a period of time (Reason, 1997). Therefore, Value Stream Mapping has the potential to be adapted so that it not only identifies non-value-added activities and waste but also highlights opportunities where both value-added and safety could be simultaneously improved. Conversely, it could also illustrate activities that are prone to human error and raise awareness of where waste elimination activities may have an adverse affect on safety. The use of Value Stream Mapping is valid for both airline and aviation maintenance operations given that safety is a key component of customer value in both of those domains.

Standard Work

Lean operations are based on the premise that tasks should be performed in line with procedures based on current best practice. Therefore, all operators should be capable of performing the same tasks in the same way every time. A standard operation includes "what" has to be done and "how" it should be done. Standard work can be supported by Value Stream Maps, by providing operators with visual, easy-to-understand procedures at their point-of-work, and by providing appropriate training. Standard work helps to ensure consistent outputs in terms of time, quality, cost and delivery.

Standard work is an approach that is also common to human factors. As mentioned with regard to Value Stream Mapping, task analysis involves a detailed understanding of individual tasks and the potential for associated human error. In addition, the provision of clear, visual instructions at work stations may reduce the errors caused by poor documentation and manuals which are often contributors to aircraft accidents and incidents (JAA, 2001; Reason and Hobbs, 2003). Therefore, a combination of lean and human factors approaches has the potential to improve both operational efficiency and safety.

Poka Yoke (Mistake-proofing)

Poka yoke is an approach to ensure that mistakes or non-compliances do not occur. This can be achieved in a number of ways, e.g. using checklists to ensure that tasks are performed in a particular sequence and that all steps in the sequence are completed, using guide pins to ensure parts can only be assembled in the correct way, through effective design of products and/ or processes, or by incorporating limit switches that sense the absence of a part (Hirano, 1995; Hinckley, 2001). Poka yoke mechanisms can either prevent errors from being made or draw attention to the fact that an error has been made. This enables processes to operate more smoothly, improving product or service quality and reducing the need for rework.

Poka yoke is a very clear example of the close alignment between lean and human factors thinking. Poka yoke tries to reduce the reliance on human memory and actions to ensure that defects cannot occur. Human factors is heavily focused on error capture, error prevention, error elimination and error tolerance. For example, aircraft flight decks are very carefully designed to ensure that the flight crew use the instrumentation and systems in the correct manner. In addition, checklists are used to ensure that flight operations tasks have been completed and conducted in the right sequence, and to assist flight crew in unusual or unfamiliar situations.

Process Capability/ Six Sigma

Once a lean process has been established, it is important that process capability is maintained and that process variability is reduced. Process capability can be improved by undertaking Root Cause Analysis and employing statistical process control methods, such as Six Sigma. Root Cause Analysis is a method for investigating the real causes of problems within an organisation and the "5 Whys" is a tool that can be used to achieve this. The underlying philosophy here is that if you continuously question the causes put forward as to why a problem exists, you will eventually arrive at the correct cause. Statistical process control methods, such as Six Sigma, can then be used to resolve recurrent defects. Other tools, such as 5S, visual management and standard work should be well established prior to embarking on a sophisticated Six Sigma programme. Six Sigma has its foundations in statistics and, therefore, relies on hard data to drive improvements – supporting a "manage-by-facts" approach. Six Sigma was originally used to ensure that machines produced products which were in conformance with strict design tolerances. However, the concept has now expanded and is used as a way of reducing many forms of variability.

In the aviation industry, aircraft accident and incident investigations are used to establish the causes of these events and identify the contributory factors, many of which are linked to human error and error-provoking factors in the workplace (e.g. www.aaib.gov.uk). This is further supported by voluntary incident reporting schemes within organisations and at national and regional

level (e.g. http://asrs.arc,nasa.gov; www.chirp.co.uk). Industry trends are monitored so that defences against recurring errors can be put in place. This process has parallels with Root Cause Analysis. However, this reactive approach to accident and incident investigation, while remaining important, is increasingly being complemented by more pro-active approaches. Six Sigma is an approach which provides both airlines and maintenance organisations with an opportunity to design robust, error tolerant processes based on quantitative data which will both reduce risk and enhance safety.

Kaizen/ Continuous Improvement

Kaizen events are fundamental to the implementation of the continuous improvement activities highlighted by activities such as Value Stream Mapping and Six Sigma. A kaizen activity involves establishing small teams to address specific issues that need to be resolved. Kaizen teams analyse the problem in-depth, recommend solutions and then proceed with the implementation of an agreed solution. Often kaizen teams will come up with simple, low-cost solutions which can implemented within short time-scales. Introducing a kaizen/ continuous improvement philosophy requires managers to take on more of a coaching role that supports employee empowerment as well as team-based working.

The introduction of kaizen within airlines and maintenance organisations has the potential to radically improve both efficiency and safety. Although accident investigation and incident reporting schemes are designed to ensure that changes are made both at organisational and industry levels to improve safety, kaizen has the potential to engage a wider range of stakeholders in a more pro-active manner, thus bringing human factors and safety issues into day-to-day business activities. Engagement in kaizen teams gives employees exposure to new ideas and other disciplines which may lead to innovative solutions to problems. In addition, the continuous improvement approach can lead to improved communication, teamwork, skill advancement and organisational learning. Furthermore, kaizen events could reinforce the safety culture and discourage undesirable behaviours.

Using Lean Tools to Support Human Factors and Safety

It is clear from the examples above that lean tools have significant potential to support human factors programmes and safety management. However, for the aviation industry, it is important that the human factors and safety benefits associated with the use of these tools is made much more explicit. This will then enable airlines and maintenance organisations to implement lean-safe operations with confidence, knowing that operational improvements have taken account of all potential human factors and safety implications.

CONCLUSIONS AND IMPLICATIONS

The aviation industry is under pressure to simultaneously improve productivity, enhance safety and ensure sustainability, resulting in the emergence of a lean-safe-green agenda. Integrating lean operations with aviation human factors and safety management represents a potential solution to the lean-safe challenge, promising the achievement of operational excellence without compromising safety. This paper has expanded on the lean-safe operations management concept by proposing a Lean-Safe Aviation Enterprise Model (LeSAM). The LeSAM provides a framework to support enterprise-level lean-safe initiatives. In addition, this paper has demonstrated how lean tools can be used to simultaneously address operational and human factors issues. In essence, the paper concludes that existing lean principles, practices and tools can be relatively easily adapted to incorporate aviation human factors and safety management approaches.

This paper has widespread implications for both theory and practice. From a theoretical perspective, it combines two distinct, and previously independent, disciplines to provide a solution for a critically important industrial challenge. It, therefore, has the power to act as a catalyst for further conceptual and empirical studies to clarify the lean-safe operations concept and the

associated principles, practices and tools. In addition, the applicability of lean to safety-critical industries can be investigated. Furthermore, the extension of the lean-safe concept to the lean-safe-green concept, incorporating the sustainable aviation challenge, raises very interesting research opportunities.

In practice, lean-safe operations management is likely to have significant implications. It will enable airlines and MROs to undertake operational improvement initiatives, confident that safety will not be compromised as a result. This approach has the potential to trigger efficiency and safety benefits at the individual employee, organisational and sectoral levels. It will also enhance passenger perceptions by allaying fears that low-cost equals increased safety risks. Furthermore, this work has implications beyond the aviation industry. Other safety-critical industries, such as medical, rail and nuclear, may also benefit from a lean-safe approach.

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