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# SAFETY MANAGEMENT SYSTEMS (SMS) for AIRCRAFT MANUFACTURERS AND MAINTAINERS?

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THESIS

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# ABSTRACT

There is much dialogue in the global aviation industry about Safety Management Systems (SMS) and how it should be integrated across all domains of the industry including aircraft design, production, flight operations, overhaul and maintenance, suppliers, service providers, airports, and so forth (Johnson, 2012).

Regulators have made significant progress in recent years to implement ICAO's SMS into airlines, albeit as a required or recommended practice. More recently the regulators are seeking to implement SMS into the aircraft manufacturing and aircraft maintenance domains.

This research reviewed regulatory publications from multiple countries to assess the technical makeup of SMS, and understand what regulators are requiring, or recommending, and when. It was found that global regulators accept the ICAO published definition of SMS, but different regulators have varying approaches regarding implementation. However, they are consistent in initially targeting airlines for SMS implementation. SMS comments range from "The best thing since sliced bread" to "Worst thing since the creation of the FAA; I don't need anyone telling me what's safe when I already know it; waste of time and money".

This investigation experimented with field tests to connect the engineering, production and airline domains into one ICAO SMS model. Results indicate that because the different domains are risk-specific, the application of one safety risk management model to all domains is not viable. The SMS model applies to airlines because airlines' primary risk is about operational *safety*. Aircraft production and maintenance is about production risk – therefore the risk model must be centric to *process* risk. Field test 3 tailored the ICAO SMS risk architecture to assess and mitigate process risk as applicable to the aircraft manufacturing and maintenance. Although the SMS architecture was usable, the content and focus was significantly adjusted to be production process-risk centric, to the point where the term "SMS' was deemed out of place. The resulting model was therefore named Production Risk Management System (PRMS).

Following the emergence of PRMS from field tests, this investigation reviewed industry, research and regulatory arguments for and against SMS in the airline industry, and correlated those arguments with the benefits and non-benefits of PRMS for the manufacturing and aircraft maintenance domains.

The researcher advocates PRMS as a viable model that meets ICAO SMS-like architecture for aircraft production and maintenance. Methods were identified for developing and implementing PRMS, and for evaluating its ROI. If and when "SMS" is truly mandated in these domains, the researcher proposes PRMS as a viable model that should be considered. Furthermore, the researcher proposes that PRMS can be an effective production risk management system that can enhance the organization's existing QMS, regardless of "SMS" regulations.

## KEYWORDS

Human factors, reactive, proactive, risk, assessment, regulatory, EASA, IATA, FAA, CAA, ICAO, JCAB, MRO, AMO, rulemaking, aviation, nuclear, Quality Management Systems (QMS), ISO9000, ISO9001, production, culture, transportation, Failure Modes and Effects Analysis (FMEA), Obeya, hazard, assurance, aviation, airframer.

## ACKNOWLEDGEMENTS

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Furthermore, my appreciation extends to Professor Graham Braithwaite and Cranfield University staff. Their attention to supporting this research, notwithstanding the challenges of long-distance / overseas communication and coordination is invaluable.

Finally, I owe a very special thank you to my family and friends. They stood back on many occasions while my nose remained buried in this computer screen, and were ignored while I stayed focussed on “production risk”. With this research concluded, I look forward to spending time doing “normal” things and showing my children that I really can watch a football game, and do something other than research and write.

## DISCLOSURE

This thesis and conclusions are solely the work and observation of the researcher. The researcher does not represent in any manner the policies, positions or opinions regarding or related to SMS, held by any person, company, agency or entity affiliated with the researcher for the purpose of this thesis.

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## Glossary

| | |
|---|---|
| AMO | Approved Maintenance Organization |
| ANPR | Advanced Notice of Public Rulemaking |
| AP | Airline Risk |
| A&P | Airframe and Powerplant |
| ARC | Aviation Rulemaking Committee |
| ASAP | Aviation Safety Action Program |
| ASIAS | Aviation Safety Information Analysis and Sharing |
| ATC | Air Traffic Control |
| ATOS | Air Transportation Oversight System |
| ATO | Air Transport Association |
| AFS | Flight Standards Service |
| AVS | Administration (FAA) Aviation Safety |
| CAA | Civil Aviation Authority |
| CASA | Civil Aviation Safety Authority |
| CFR | Code of Federal Regulations |
| CASO | Commercial Air Service Operations |
| C of A | Certificate of Airworthiness |
| CI | Continuous Improvement |
| EASA | European Aviation Safety Agency |
| ERMS | Engineering Risk Management System |
| FAA | Federal Aviation Administration |
| HF | Human Factors |
| IATA | International Air Transport Association |
| IP | Installation Plan |
| IAEA | International Atomic Energy Agency (IAEA) |
| ICAO | International Civil Aviation Organization |
| IFPPF | Instrument Flight Procedure |
| INSAG | International Nuclear Safety Advisory Group |
| IPT | Integrated Product Team |
| IT | Integrated Technology |
| ISO | International Organization for Standardization |
| JCAB | Japanese Civil Aviation Bureau |
| JPDO | Joint Planning and Development Office |
| MEDA | Maintenance Error Decision Aid |
| MR&O | Maintenance Repair & Overhaul |
| MTBF | Mean Time Between Failures |
| NGATS | Next Generation Air Transport System |
| NCR | Non-Conformance Report |

| | |
|---|---|
| NPRM | Notice of Proposed Rulemkaing |
| NRC | Nuclear Regulatory Commission |
| NRR | Nuclear Reactor Regulation |
| ORM | Operational Risk Management |
| PA | Production Assurance |
| PC | Production Certificate |
| PCM | Production Culture Management |
| PDCA | Plan-Do-Check-Act |
| PMA | Parts Manufacturer Approval |
| PR | Production Risk |
| PCM | Production Culture Management |
| PRMP | Production Risk Management Panel |
| PRMD | Production Risk Management Document |
| PRMDM | Production Risk Decision Memo |
| PR | Production Risk |
| PRM | Production Risk Management |
| PRMS | Production Risk Management System |
| QA | Quality Assurance |
| QC | Quality Control |
| QMS | Quality Management System |
| RM | Risk Management |
| RPN | Risk Priority Number |
| ROI | Return On Investment |
| SA | Safety Assurance |
| SARPS | Standards and Recommended Practices |
| SME | Subject Matter Expert |
| SMM | Safety Management Manual |
| SMS | Safety Management Systems |
| SMS PP | SMS Pilot Project |
| SPC | Senior Policy Committee |
| SR | Safety Risk |
| SRM | Safety Risk Management |
| TC | Type Certificate |
| TEM | Threat and Error Management |

# 1.0 Introduction

## 1.1 SMS Background

SMS is a term that has various definitions subject to the person or organization using it. Generally it is interpreted as applying a quality management approach to control safety risks. Similar to other management functions, safety management requires planning, organising, communicating and providing direction. Some definitions are concise such as the FAA's and ICAO's, while others are lengthier and include reference to organizational culture. However, SMS categorization and intent across industries is consistent. Whether applied to nuclear, chemical, marine, aviation, or others – SMS has become a methodology that is recognized by practitioners as an industry practice that some would argue is an industry standard closely allied with organizational QMSs. While high-level SMS definitions are universally consistent, the technical details and implementation strategies that constitute a functioning SMS vary subject to the industry. It is these details that cause philosophies of what SMS is to vary. Some high-level descriptions are as follows:

"A businesslike approach to safety. It is a systematic, explicit and comprehensive process for managing safety risks. As with all management systems, a safety management system provides for goal setting, planning, and measuring performance. A safety management system is woven into the fabric of an organization. It becomes part of the culture, the way people do their jobs" (LaFlamme, 2001).

"SMS is an organized approach to managing safety, including the necessary organizational structures, accountabilities, policies, and procedures" (ICAO, 2006).

"An SMS provides a systematic way to identify hazards and control risks while maintaining assurance that these risk controls are effective" (FAA, 2009).

"For the purposes of defining safety management, safety can be defined as the reduction of risk to a level that is as low as is reasonably practicable. There are three imperatives for adopting a safety management system for a business – these are ethical, legal and financial" (Karuppasamy & Venkadesh, 2011).

"A Safety Management System is the most effective way to improve safety in any aviation organization (operators, manufacturers, maintenance providers, air traffic control, training providers, etc). It is a systemic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures. In other words an SMS assures that an aviation organization is organized, structured and clearly documents and implements all the aspects necessary to be effective in the operational environment" (Fuentes, 2012).

## 1.2 SMS Context and the Aviation Industry

The Three Mile Island accident was a partial nuclear meltdown which occurred in one of the two Three Mile Island nuclear reactors in Dauphin County, Pennsylvania, United States, on March 28, 1979 (U.S. Nuclear Regulatory Commission, 2013). It was the worst accident in U.S. commercial nuclear power plant history, and resulted in the release of radioactive gases and radioactive iodine into the environment (Walker, 2004). Questions were subsequently asked such as "Why did we not foresee the problem before it became an accident?" "Can a methodology be developed that could predict the likelihood of an issue within the organization and proactively make adjustments to avoid prospective incidents and accidents?" Human factors became a key aspect of understanding and quantifying risk, in conjunction with the culture of the organization.

The United States Nuclear Regulatory Commission's (NRC) investigation stated that "*The one theme that runs through the conclusions we have reached is that the principal deficiencies in commercial reactor safety today are not hardware problems, they are management problems*" (Rogovin, 1980). Later, the NRC established the Division of Human Factors Safety in the Office of Nuclear Reactor Regulation (NRR) and the Human Factors Branch within the Division of Risk-Analysis in the Office of Nuclear Regulatory Research. These branches became responsible for addressing human factors issues in operator licensing, procedures, human-systems interface, training, staffing, and management.

The term “safety culture” came about after the Chernobyl nuclear power-plant accident in 1986. The ensuing investigation concluded that the management attitude was a significant contributor to the chain of events leading to the accident (International Nuclear Safety Advisory Group, 1992). INSAG stated in its post-accident report that “*The vital conclusion drawn is the importance of placing complete authority and responsibility for the safety of the plant on a senior member of the operational staff of the plant*.” INSAG went on to name safety culture among the fundamental management principals along with the responsibilities of the operating organization and the provision of regulatory control and verification of safety-related activities.

The Three Mile Island and Chernobyl accidents brought attention to the need for a form of systemic risk management that is predictive, proactive, non-punitive, repeatable, has executive management accountability, and is centric to safety culture - all aspects that over subsequent years became cornerstones of SMS philosophy and architecture. As SMS became defined and formalized, other areas adapted the philosophy including the maritime industry (International Maritime Organization, 1993), and railway companies in 2001 under Transport Canada (Bourdon, 2011).

In the mid 1990s the FAA along with other aviation regulatory bodies worldwide took note of SMS philosophy. They recognized the value of SMS as a methodology that could reportedly predict the likelihood of a risk event and proactively made adjustments, rather than taking the decades-old reactive approach of primarily mitigating after an incident or accident investigation. In the late 1990s ICAO and the FAA began considering SMS for CFR Part 121 airlines (Larson, 2010). Although the reactive method for improving safety was shown to be effective, there was still a need for a method or system that would help identify latent conditions to accidents before they actually occurred. In order to support the implementation of this new approach to the management of safety, the ICAO Safety Management Systems (SMS) program was launched in 2004

(ICAO, 2009). Since then SMS has been consumed with varying degrees of success and has become a recognized term across the aviation industry. Now, as aviation SMS moves closer to regulatory mandate, debates continue that while recognizing the intent of SMS, deliberate over all aspects including how to implement the architecture, how to manage the data, and what SMS ROI benefits are, or are not (Collogan, 2011).

A central argument is that many or all features of SMS are already embedded within an airline’s traditional QMS, and organizing into an SMS structure may be redundant (Burchell, 1 May 2011). Aside from discussions about the operational practicality and implementation costs, SMS is generally recognized as beneficial to airline operational safety management and to their business/economic model. For example, Civil Aviation Authority, United Kingdom in 2004 recognized the value of a safety management system as “the systemic management of risks associated with flight operations, related ground operations and aircraft engineering or maintenance activities to achieve high levels of safety performance” (Gill & Shergill, 2004). Notwithstanding the pro and con debates, SMS has become an aviation industry standard that is part of administrative oversight – albeit required or voluntary depending on the state regulator.

Although airlines have varying views of SMS, in recent years its prospective integration with aircraft manufacturers’ and MROs’ has received increasing regulatory attention. If a path is taken that is similar to airline SMS implementation, ICAO will issue a Standards Recommended Practices (SARPS) stating that manufacturers “shall establish and maintain an SMS that is appropriate to the size and complexity of the operation” (National Business Aviation Association (NBAA), 2014). As with airline SMSs, some state regulators may implement SMS for manufacturers and MROs ahead of others, which would become a source of concern for countries and business enterprises that are not yet ready for such change.

## 1.3 Research Objectives

Now that SMS is taking hold with airline regulators, the aviation industry at large is considering how SMS can be implemented across the entire airplane lifecycle - from cradle to grave. In addition to airline operations, this encompasses aircraft manufacturing, and aircraft maintenance and repair (Prentice, 2013). This research investigates the ongoing conversations and challenges of applying SMS philosophy to said manufacturing and MRO domains of the airplane lifecycle [Figure 1-1].

Discussions of SMS in the aviation industry have been ongoing for several years, but dialogue of its application to the production and MRO domains is more recent. The airline domain generally embraces SMS as another tool for improving safety, and one may anticipate manufacturers as seeing it as one for improving production risk. Doug Carr, FAA says there appear to be three camps that emerge regarding SMS: (1) “Love it; best thing since sliced bread; can’t get enough,” (2) “Not sure if I need it, but we’ll do it because we can’t face the question from the boss about why [some country] won’t let us in and (3) “Worst thing since the creation of the FAA; I don’t need anyone telling me what’s safe when I already know it; waste of time and money” (Collogan, 2011). It is likely that similar camps will emerge with manufacturers and MROs as SMS becomes targeted for these domains.

Doug Car stated that ICAO adopted SMS language in 2008 “as a leading edge concept that a lot of people just weren’t ready for yet …. And as a result it will most likely be many years before countries and aircraft manufacturers adopt some form of SMS with its inherent complexities. But as a community practice, airlines’ QMSs are 80-90% toward an SMS. The difference between where airlines’ SMSs and QMSs are, and where they need, to be is probably pretty small” (Collogan, 2011). The aviation industry anticipates significant growth in the amount of flying in upcoming years, and SMS is seen as a proactive methodology to lower the accident rate. Conversely, manufacturers will need to increase production rate to support the growth – and a form of SMS is arguably a proactive tool to support production rate increases while further managing production risk.

This research explores key questions of SMS application with manufacturers and maintainers: Safety of flight can directly impact people. Manufacturers produce airplanes but manufacturers do not fly airplanes – so should SMS reside exclusively with the airlines? Is there a direct correlation between a production risk event and an in-service airline risk that one holistic airplane life-cycle SMS architecture can capture? Can SMS airline domain architecture and philosophy apply to, or be tailored, to the aircraft production domain? Just as airline QMSs are 80-90% toward an SMS – is a manufacturer's QMS already very close to an SMS? If so, is "SMS" redundant in the production environment? If SMS does not fit the production domain, can some form of SMS be tailored to fit – and if so – would SMS purists contend that it is not really SMS and it should take on a different and more applicable production-centric title?

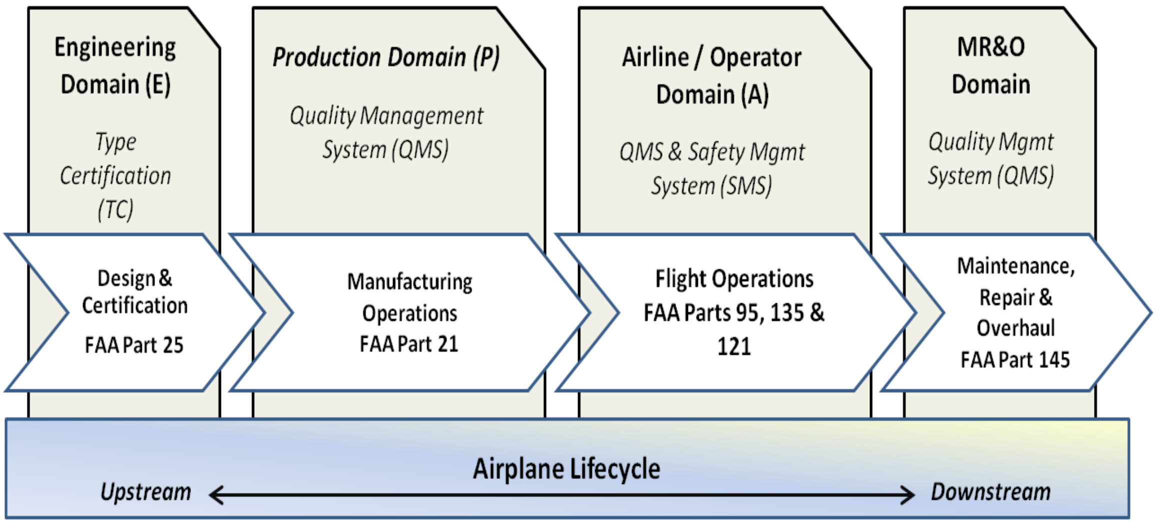



**Figure 1-1. Airplane Lifecycle Domains**

## 1.4 Research Methodology

This thesis is supported by an examination of aviation regulatory and industry developments and philosophies, field tests within an aircraft manufacturing company, and the researcher's career of over twenty-five years of employment with airlines and aircraft design and manufacturing companies.

In 2007 a commercial aircraft caught fire and exploded after landing and taxiing to the gate area. All 157 passengers escaped, and 4 people (three from the aircraft and one ground crew) sustained injuries. Fortunately there were no fatalities. Subsequently an FAA inspector asked if airline SMS methodology, if applied to the aircraft production domain, could have prevented the accident. The inspector's question is central to the research methodology.

To address this question the researcher investigated data flow from the manufacturer's QMS and the airline's QMS to identify potential data correlations. The existing regulated QMSs both in the manufacturing and airline domains are robust, having been in place for decades. There are multiple safety and process filters within airline operations, and multiple production control procedures and filters within aircraft manufacturing systems.

To evaluate if and how existing data may be organized into an "SMS" format, the researcher gained a charter from executive management at an aircraft production company. The charter provided for an IPT to support research of how SMS may or may not enhance the existing production QMS.

Before field tests took place, the researcher initiated the IPT with overviews of SMS concepts and talked about how SMS methodology correlates data intelligence with human factors input. An overview of all production datastreams was reviewed, and the researcher hypothesized that this existing quantitative data coupled with qualitative human factors information from production line mechanics may support an SMS-like model.

Quantified production datastreams are currently incorporated with the QMS, while qualitative human factors information about aircraft build practices is less formulated. To enhance human factors information, the researcher selected the fuel systems installation commodity and organized "process walks" with the commodity mechanics. This required a close relationship with production personnel and supervisors. Questions were asked of mechanics in a constructive non-threatening manner, and expeditiously so as not require unreasonable time. Relationship building with production personnel was essential in order to gain trust and continued support, and mechanics were added to the IPT.

SMS requires a repeatable process, and initially production process walks were based on the Obeya model. However, this model did not provide adequate focus for a specific commodity type, so standard process walk questions were established by the IPT. Human factors inputs were based on process walk observations and correlated with existing production data, as a function of the specific production commodity.

A FMEA matrix was selected to associate information from the domain types – i.e. engineering, production and airline. SMS defines risk as a function of the likelihood of a negative event and the severity of that negative event manifesting. With inputs from Engineering (E), Production (P) and Airline (A) data in a FMEA matrix, the researcher experimented with a resulting Risk Priority Number to represent lifecycle EPA risk.

Iterative field tests were conducted to evaluate the value and practicality of linking the aircraft lifecycle domains into one FMEA matrix. The third field test provided data specific to the manufacturing domain that was then transcribed to SMS architecture. Given that the data was exclusively production-centric, the model was named PRMS, and the details of PRMS were developed.

PRMS as an SMS-like system was benchmarked against regulatory and industry SMS implementation challenges, and a conclusion was drawn as to whether or not SMS is applicable to aircraft manufacturing.

## 1.5 Structure of the Thesis

Chapter 1: Introduction

This chapter lays out the setting for the research. It introduces SMS as defined by various industries, and provides an oversight of its origins and makeup, and how it adapted into the aviation business. It introduces arguments for and against SMS as applicable to different domains of the aviation industry.

Chapter 2: Composition of Industry Regulations

The key objective of Chapter 2 is to assess global SMS regulations that have been and are taking place, and understand how state regulators are responding to them. Beyond reviewing the regulatory push, this chapter identifies the SMS definition that is globally recognized by the aviation industry, and thereby establishes a baseline SMS description for this research. The ICAO definition is accepted by regulators globally. ICAO requires member states to implement SMS with airlines, and is moving towards requiring it of all domains of the airplane lifecycle at some future time. The objective of Chapter 2 includes the review ICAO's Safety Management Manual (SMM) and SMS architecture, and State regulator's responses to ICAO's SMS goals. The chapter reviews the complexity of implementing SMS from a regulatory perspective, including the Notice of Public Rulemakeing (NPRM) process that the FAA uses to gain industry comments ahead of implementing a significant requirement. The review includes regulators such as the FAA, UK CAA, Transport Canada, and CAR. By seeking to understand the composition of the industry, the foundation for this research is laid.

Chapter 3: Methodology

This chapter describes the approach that is taken for field tests. It includes an overview of the researcher's membership with the U.S. JPDO organization that aligns U.S. aviation SMS policy with ICAO SMS definition, and by gaining first-hand knowledge of the JPDO forum the researcher seeks to ensure that field tests are copasetic and consistent with the technical aspects and risk definitions that are embedded in SMS architecture [Appendix A]. The chapter describes the charter, from executive management of an aircraft production company, to engage an IPT. The IPT was used to experiment with methods for assessing an SMS model that prospectively connects the three domains of the aircraft lifecycle, then for just the production and airline domains, and finally to assess production risk exclusively within the production system using SMS-like architecture.

Chapter 4: Field Tests

This chapter begins with a review of what a single point of failure is within a production system, and within an airline. It provides definition of what a holistic airplane lifecycle SMS is, and introduces ICAO's method for quantifying risk as a function of the Likelihood of the risk taking place, and the Severity of that risk if left unchecked – or manifesting. The chapter lists by job title the members of the IPT, and describes the 3 field tests and results.

Field Test 1 experiments with identifying a single point of failure (or risk) with engineering-to-production-to airline data using SMS-like architecture.

Field Test 2 experiments with identifying a single point of failure with production-to-airline data using SMS-like architecture.

Field Test 3 experiments with identifying a single point of failure exclusively with production system data using SMS-like architecture.

The Field tests are evaluated to determine if an SMS architecture can be used for the production system, and if the architecture should be revised (relative to pure SMS) to focus on the type of risk that is exclusively a function of the production system. The term PRMS is created to describe a system that identifies production risk (PR) within a manufacturing domain, and that is in the context of SMS-like architecture.

Chapter 5: ICAO and Production Risk Management System (PRMS) Model

Chapter 5 evaluates each detail of the SMS's architectural components and elements, and translates them into PRMS context. By establishing a PRMS definition for each of the elements, the research seeks to create a repeatable model that can be used for PR with aircraft manufacturers and maintainers, and that uses ICAO-style risk assessment and risk tolerability matrixes.

Chapter 6: Discussion and Evaluation of PRMS

This chapter evaluates why an unaltered SMS does not fit into a production domain. It looks at definitions of process risk versus safety risk, and how types of risk should be assessed. The chapter reviews industry literature that supports the concept of an overall airplane lifecycle SMS, and reviews literature that opposes it given that the risk types are different. A PRMS implementation strategy is developed and assessed by benchmarking against SMS implementation strategies, as is a conceptual assessment of PRMS implementation costs and benefits, and potential liabilities.

Chapter 7: Current Status of FAA SMS Regulations

Chapter 7 revisits the FAA's position with SMS to compare where its regulations are now, relative to were the FAA was when this research began. The chapter shows reviews the mandate for airlines to have Part 5 SMS in place by 05/12/14. Over recent years, 94% of Part 135 and 121 air carriers participated in a voluntary SMS implementation. Knowing that the FAA would at some point mandate SMS, the carriers did not want to be caught flat-footed when the mandate finally came through. Conversely data shows that only 0.3% of MRO facilities have participated in voluntary SMS. And given that it took many years for SMS to be mandated with airlines, maintenance organizations and MROs may expect a similar time span before a similar mandate is applied to them.

Chapter 8: Conclusions

This chapter provides a summary of the thesis. It addresses the effectiveness of the research methodology and suggests further areas for study. It considers areas of research that were most challenging, and how my initial thoughts aligned with research.

# 2.0 Composition of Industry and Regulations

## 2.1 Why Investigate SMS in the Aviation Industry?

SMS refers to a managed system that proposes to overarch and integrate all safety activities in the industry. It is arguably applicable across all domains that include predominant aircraft manufacturers such as Boeing and Airbus, large airlines, regional carriers and small private operators, small and large aircraft maintenance providers, and suppliers of all types, size and complexity. "The requirement for SMS is aimed at every enterprise touching aviation, from manufacturers to aircraft operators, FBOs and maintenance shops" (Larson, 2010). Beyond general acceptance of what SMS is, can be or should be, there is variance in the philosophy and details of SMS composition, and if it can in practicality be applied across all domains in its purest form.

Aircraft manufacturers, commercial airline operators, MROs and aviation regulators are not uniform in their interpretation, implementation and rulemaking of SMS. For example, Transport Canada currently requires airframers to implement SMS under (Transport Canada, 2003). Other regulators such as the FAA have yet to require 14 CFR Part 25 *airframers* to implement an SMS, but the FAA does require SMS of *airlines* under its jurisdiction. The FAA applies ATOS as its tool to gather maintenance and flight operational data for oversight, which is also used to verify the effectiveness of airlines' SMSs. If SMS is applied to manufacturers one may then question if ATOS (an airline-derived assessment tool) should be modified to encompass aircraft production.

Major airline operators hold a "Part 121" certificate. Implementing SMS into this one domain has a clear boundary – flight operations. However, some operators also hold a "Part 145" certificate which allows them to maintain their own (and or other operators') aircraft. In such cases the airline enterprise has two different domain-types to manage – flight operations and maintenance operations. SMS implementation becomes convoluted since the two domain types have different, but overlapping, primary functions. Regulators struggle with the application of SMS with airlines that include the Part 145 certificate in terms of how to apply SMS that is architected around flight safety into an organization that also includes maintenance, and how to integrate and interface the two different primary functions within that one business enterprise.

The question becomes more convoluted for manufacturers of large commercial airplanes who hold multiple certificate types. Manufacturers such as Boeing and Airbus hold Part 21 certificates that regulate their primary function – aircraft production. But due to a business environment that has become increasingly integrated, such manufacturers are directly and indirectly influenced and regulated by other certificates such as Part 91 (Aircraft Operations / Flight Test), Part 141 (Training), Part 145 (MR&O), and Part 121 (Scheduled Passenger Service Operations). These certificate types overlap and interface with the manufacturers' primary business, and complicate the process of defining and implementing *one* SMS into aircraft manufacturing enterprises [Figure 2-1].

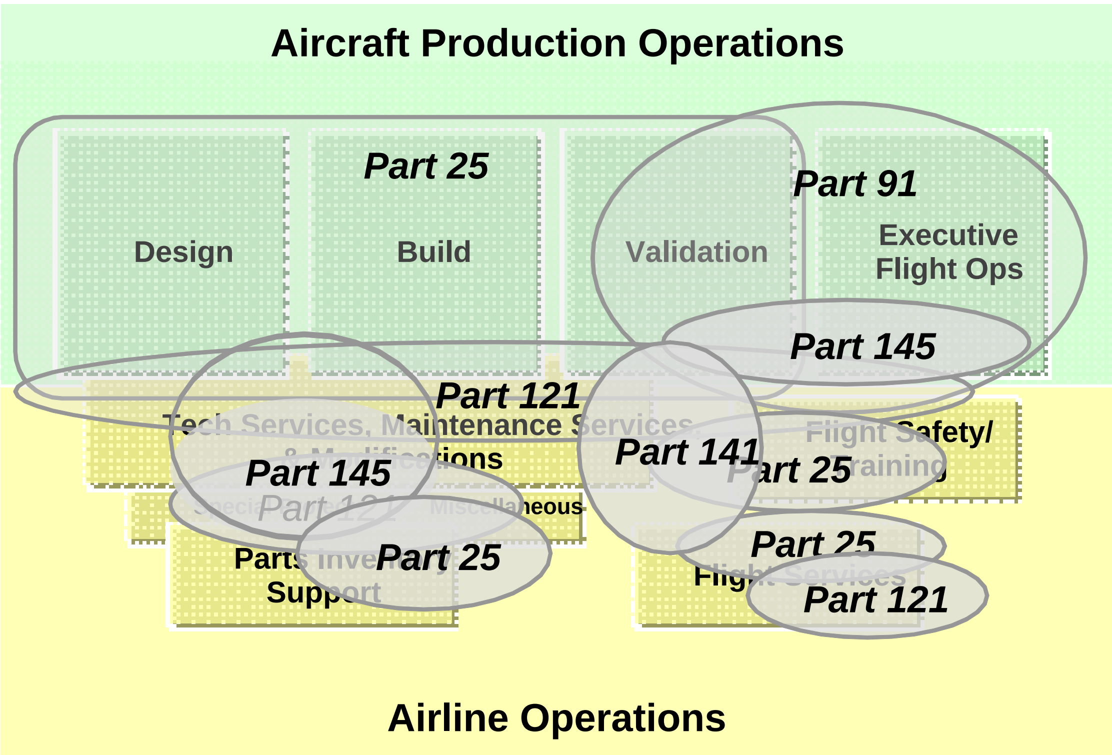



**Figure 2-1. Industry Domain Certificates that Influence the Manufacturer**

Airline operators, manufacturers, maintainers and service providers are referred to as high-risk industries, or high-risk domains (Grote, 2012). The safety literature for high-risk industries is dominated by studies involving large machine-bureaucratic organizations, such as nuclear and chemical industries, often with very considerable investment. Civil aviation, on the other hand, has generally received less focus, yet few industries can rival the growth, introduction of new technologies, and increase in complexity that the civil aviation industry has experienced over the past years, and will experience in the future (Shin, 2005). The civil aviation industry can be described as a complex system of overlapping socio-technical systems embedded within a highly competitive business environment, where safety is a primary, but not the only, goal. It is an arrangement of interfacing systems where external actors can obscure or mask system deficiencies that can lead to the development of latent conditions (Lofquist, 2010).

This research explores the feasibility of an aircraft production-centric SMS model to meet the generally accepted ICAO SMS definition. It addresses the SMS alignment of multiple certificates that overlap with the production enterprise, including the arrangement of policies and practices with an integral set of analytical tools and documented processes. To meet ICAO intent, the production “SMS” model should be capable of incorporating regulatory certificates and processes that they are already subject to, and it should be compatible with global SMS standards. In the spirit of SMS, the model should dually serve as a tool to help optimize the production enterprise, and be capable of integrating with a globally connected data network that is proposed for the future SMS world (Darr, et al., 2010).

The prospective model should include a formal, top-down business-like approach. To meet SMS context it should include systematic procedures, practices, and policies that align with risk management, safety policy, safety assurance, and safety promotion – the four generally accepted components of SMS architecture. It should align with established SMS protocols to ensure that risks in each department collectively correlate with the manufacturing enterprises' outputs, and that the enterprise can simultaneously align with globally emerging SMS developments and existing regulations.

Large commercial transport airlines have a highly commendable safety record, but the probability of risk occurrences that involve hull loss increase with the number of aircraft delivered into service each year (Cokorilo, et al., 2010). In 2011 the United States broke all safety records having gone for nearly three years without an airliner accident fatality. The accident rate worldwide was also down considerably (Dr. Johnson, 2012). And as of 2013, even with nearly 80,000 flights each day within the U.S. national airspace system, there had not been a fatal commercial aviation accident in more than four years. The U.S. airspace system is arguably one of the safest in the world, with key aviation stakeholders – the FAA, airlines, airports, aircraft manufacturers, and the National Transportation Safety Board (NTSB) – working together to ensure these results (Dillingham, 2013). It is argued that a holistic airplane life-cycle SMS will support continuance and enhancement of aviation safety, and will benefit all domains by structuring homogenized cross-company/enterprise efficiencies and processes, endorse timely dissemination of emerging information, and promote stronger cultures with aviation regulatory administrations. The FAA is currently pursuing SMS on two tracks – one for industry and one for FAA itself. As officials develop the internal SMS regime, it will document the steps along the way, which will serve as guidance (Infanger, 2010). The production-centric SMS model should be able to integrate with all aspects of the aircraft lifecycle from design, through production, to flight operations and aircraft maintenance.

## 2.2 General Overview

Regulatory literature searches review predominant SMS policies being developed and published. It indicates that while many regulators have, and are, issuing SMS programs and directions of varying capacity, ICAO has issued the most comprehensive guidance of all SMS publications. It is thus the most accepted SMS definition as recognized by U.S. and non-U.S. aviation administrations. This review observes that all SMS regulators require the same four components as defined by ICAO: Safety Risk: Safety Assurance: Safety Promotion: and Safety Policy. Beyond that, publications address how SMS encompasses areas such as hazards, safety risks, human factors, and organizational accidents. State Programs include implementation specificity where the Target Audience is "Representatives from civil aviation authorities with responsibilities regarding the implementation of safety programmes, and the implementation and/or oversight of safety management systems, in the areas of airline operations, air traffic services, maintenance of aircraft and aerodrome operations" (ICAO, 2008).

Aviation administrators reviewed in this paper are defining SMS as part of a comprehensive long-term aviation strategy. It is recognized that while many are reviewed in this paper, other governments that are not specifically mentioned are pursuing similar paths that address either limited-scope SMS programs, and or programs that incorporate SMS in conjunction with more wide-ranging NGATS components.

## 2.3 Alignment with multiple US 14 CFRs

Regulators such as the FAA issue SMS communiqués that are specific to FAR 14 CFR "Parts" – also referred to as "Certificates". A Maintenance Repair & Overhaul (MR&O) station/depot operates under a Part 145 Certificate. Major airlines operate under Part 121 (scheduled passenger service operations), and an Airframer's primary business of design and production are under Parts 25 and 21. An airframer also holds certificates for areas including Training (Part 141), Flight Test (Part 91), and Part 145 if the airframer also operates repair stations.

Since FAA SMS communiqués are specific to certificates, and the certificates vary according to the aviation domain, regulatory communiqués are released independently, that is, they are domain specific. In addition to being independent, the domains are not receiving prospective rules at the same time. In fact years are passing between the application of SMS into the airline domain versus the MRO and the manufacturing domains. MROs have received prospective SMS rules years after the airlines – and the rules are to date not enforced. And Part 21 airframers have yet to receive SMS rules, although there is discussion with regulators as to how SMS can be applied to this domain. This presents a dilemma for the airframers who typically hold multiple certificates. The policy is designed to be systemic. It requires an accountable executive to be identified for the entire enterprise, and it requires each of the enterprises' departments to fulfil a clearly defined role in the SMS system (U.S. Department of Transportation, 2004). The issue an airframer faces is that while some SMS certificate requirements are identified by the regulator, SMS definitions for other certificates (i.e. Part 21) remain undefined or nebulous. So an airframer who holds both a Part 145 certificate prospectively has to define and implement an SMS methodology for its repair stations, but is not simultaneously required to implement SMS in its design and manufacturing functions. This creates the challenge of defining an SMS system for the *entire* airframer enterprise – with one "SMS accountable executive" – a stipulation of SMS implementation.

In addition to being *direct* holders of multiple certificates, airframers are also influenced *indirectly* by certificates that customers hold, i.e. Part 121 airlines. The airlines are ahead of the airframers in terms of receiving SMS communiqués from the FAA, but this still influences airframer's departments such as in-service engineering and aircraft maintenance and repair services. Thus the scenario of certificate-centric SMS communiqués rather than organizationally-centric SMS communiqués is not an issue for single certificate holders such as airlines and independent repair stations. But it is an issue for airframers who are inherently influenced by certificates both directly and indirectly.

## 2.4 U.S. Alignment with multiple governments' CFRs

U.S. based airframers with foreign customers must also align with overseas aviation regulators who have, or will have SMS requirements. Such regulators are developing SMS schedules that are independent of FAA schedules. As an example, JCAB requires a U.S. airframer that services its U.S.-built, but

Japanese registered aircraft, to implement SMS in its U.S.-based repair station. Without an SMS implementation as accepted by the JCAB, JCAB reserves the prerogative not to renew the repair station certificate. So the impact to a U.S. airframer is that it must not only somehow comply with evolving and prospective domestic FAA SMS requirements that are certificate-centric, but it must also comply with multiple foreign SMS rules in order to maintain certification from foreign regulators for services such as aircraft maintenance. And as with FAA SMS definition, foreign SMS definitions can be subjective which further compounds the challenge of creating a universally accepted SMS architecture.

## 2.5 U.S. Government / FAA / JPDO

In the late 1990s the U.S. Federal Government was advised that the air transportation system within U.S. airspace, would not efficiently support future capacity based upon projected expansion of the Department of Transportation's (civilian) and Department of Defense's (military) airspace usage.

In response, the USA created JPDO (Joint Planning Development Office) to manage the work related to the development of the Next Generation Air Transportation System (NGATS), a vision of air transportation in 2025 (USA Government, 2001).

JPDO began with eight focus working groups that included participants from industry and government. One of the groups was the Safety Group, which spun off a Safety sub-group that subsequently developed and defined the NGATS/JPDO SMS policy.

While the amalgamated NGATS (with all component programs and sub-programs) is expected to be implemented by 2025, the focus groups are defining their programs incrementally. And in turn the departments (within DoD and DoT) are, and will be, interpreting the resulting policies, and determining implementation timelines for their respective jurisdictions. An example is the SMS policy that was accepted by the JPDO Senior Policy Committee (SPC) and published in a 2008 FAA Advisory Circular (Fedaral Aviation Administration (FAA), 2008). SMS policy was published even though the implementation methodology and timeline requirements were not established by the FAA, due to various interpretations of the details by both the FAA and by the aviation industry at large. Note that although this research focuses on civilian air transport SMS (i.e. DoT/FAA), the discussion also pertains to parallel domains in the aviation defence industry.

## 2.6 Eurocontrol

SMS and long-term air transportation system strategies are not exclusive to the U.S. The European Organisation for the Safety of Air Navigation (EUROCONTROL) identified y2030 as its target to have implemented its New Generation Air Traffic System (NGATS). This is equivalent to the U.S. NGATS/JPDO program and has similar focus groups including a Safety group with an SMS policy definition as published in 2008. JPDO and EUROCONTROL are coordinating efforts with the intent of the two systems becoming interoperable. (The MITRE Corporation, 2005).

## 2.7 ICAO Safety Management Manual (SMM)

Ref. ICAO Safety Management Manual (SMM), Second Edition - 2009

The manual is an extensive guide that describes how aviation safety, reliability and quality systems have evolved from the early 1900s “technical era”, to the “organizational era” that spans from the mid 1990s to current times. This highly successful organizational era resulted in incidents and accidents becoming rare, which manifested in a movement towards a business-like approach to the management of safety. SMM Ref 3-5 …. “This business-like approach to safety underlines the rationale of safety management systems (SMS) as discussed in Chapter 7” (ICAO, 2009).

The SMM describes classic concepts of safety theory including accident causation, organizational accidents, errors and violations, and safety investigation. Most importantly it defines SMS architecture that has become the universally accepted standard by regulators.

The architecture is defined by four components: Safety Promotion, Safety Policy, Safety Risk Management and Safety Assurance. Each component contains sub-parts called Elements [Figure 2-2].

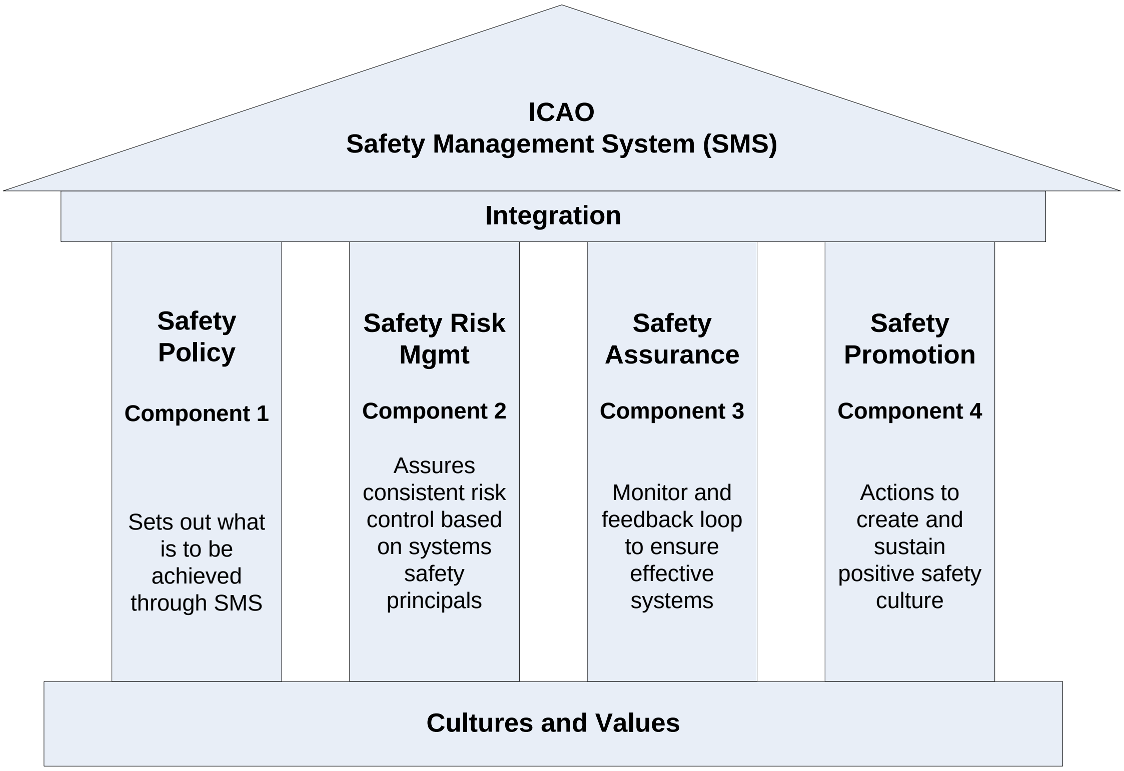



**Figure 2-2. The Four ICAO SMS Components**

<u>Component 1 – Safety Policy and Objectives</u>

Element 1: Management commitment and responsibility: commitment of senior management to safety is reflected in a policy statement signed by the accountable executive.

Element 2: Safety accountabilities: a statement of accountabilities clearly defines safety responsibilities of managers and employees at different levels in the organization with effective delegation of responsibilities established for operationally critical areas when principal office holders are absent.

Element 3: Appointment of key safety personnel: there needs to be a safety manager, tasked by the accountable executive with the daily oversight functions of the SMS.

Element 4: Coordination of emergency response planning: there needs to be an Emergency Response Plan (ERP) that includes contingency plans to ensure proper response throughout the organization when an emergency situation arises.

Element 5: SMS documentation: all safety management activities must be documented and be available to all employees.

Component 2 – Safety Risk Management

Element 6: Hazard identification: the organization must maintain processes that insure that hazards are identified for all operational activities. Hazard identification is based on a combination of reactive, proactive and predictive safety management methods.

Element 7: Risk assessment and mitigation: individual hazards are analyzed, their consequences are assessed and communicated throughout the organization. Mitigation actions must be developed for those hazards presenting unacceptable operational risk.

Component 3 – Safety Assurance

Element 8: Safety performance monitoring and measurement: safety assurance activities focus on assessing the health of the organization with an emphasis on safety. Specific goals for improvements in all areas should be set for all senior operational managers. Safety assurance should include monitoring of external sources of safety information and include participation in regional safety groups or safety data sharing organizations.

Element 9: Management of change: external or internal changes may introduce new hazards to operational activities. Processes must exist to manage organizational responses to regulatory changes, major changes in operational procedures or new activities. Safety reporting systems should have processes established to identify new risks and actively monitor performance in new areas of the operation.

Element 10: Continuous improvement of the SMS: safety assurance utilizes quality tools such as internal evaluations or independent audits to assess organizational health from a safety perspective. Onsite assessments of operational management systems on a recurring basis provide opportunities for continuous improvement of processes and procedures for each functional area of the organization.

Component 4 – Safety Promotion

Element 11: Training and education: the organization must identify safety training requirements for each level of management and for each employee group. Safety training for operational personnel should address safety responsibilities, including complying with all operating and safety procedures, recognizing and reporting hazards and ultimately ensuring that employees have the knowledge and skills to safely complete work activities.

Element 12: Safety communication: communication of safety information is a key responsibility for the safety manager but more so for the organization as a whole. Continuous improvement and learning is accomplished through the sharing of lessons learned from investigations, hazard report analysis and operational safety assessments. Feedback to operational personnel such as examples of procedural improvements as a result of safety reports is an essential feature of safety communications.

SMM Chapter 7 – Introduction to Safety Management Systems (SMS), section 7.2.7 notes that all aviation stakeholders may contribute to SMS to assist in the decision-making process on safety risks:

a) aviation professionals
b) aircraft owners and operators
c) manufacturers
d) aviation regulatory authorities
e) industry trade associations

f) regional air traffic service providers
g) professional associations and federations
h) international aviation organizations
i) investigative agencies
j) the flying public

7.2.7 invites input from all sectors and stakeholders of the aviation community, including c) manufacturers. This concurs that SMS is intended to become all-inclusive, and that while to-date there is limited specificity for manufacturers' implementation, an airframer SMS model will likely, at some point, be defined that is acceptable to U.S. FAA that also aligns with ICAO.

The SMM includes a gap analysis checklist (7-APP 2-2) that can be used as a template to help determine how similar existing organizational systems are to the ICAO SMS framework. It includes the four components (Safety Policy and Objectives; Safety Risk Management; Safety Assurance; and Safety Promotion). These are sub-divided into questions with yes/no responses that indicate where gaps exist between where the organization is versus SMS definition, and therefore suggests a foundation to begin an SMS implementation plan. Although the questions are generic and may be applicable to any domain within the aviation industry, some questions can be tailored, and other questions may be added to generate a domain-centric SMS gap analysis.

## 2.8 ICAO State Letter AN 12 / 52 / 1-08 / 70

ICAO State letter AN 12/52/1-08/70 addresses Implementation of the State Safety Programme in States (ICAO, 13th November 2008).

The letter introduces requirements for implementation of the State Safety Program (SSP). It states that SSP is a consequence of "growing awareness that safety management principals affect most activities of a civil aviation authority, including safety rulemaking, policy development and oversight". The letter introduces objectives of the SSP training course that is targeted at State Officials with responsibilities that include implementation and/or oversight of safety management systems. The course was first offered in March 2009 and includes training of SSP safety data management.

The letter is applicable to Annex 6 – Operation of Aircraft, Part I – International Commercial Air Transport – Aeroplanes, and Part III – International Operations – Helicopters, Annex 11 – Air Traffic Services, and Annex 14 – Aerodromes, Volume I – Aerodrome Design and Operations. However, the letter does not encompass Aircraft Design and Production.

## 2.9 FAA Order VS 8001.1; SMS Doctrine

Ref. U.S. Department of Transportation FAA Order VS 8000.1; SUBJ: Safety Management System Doctrine: Effective Date 08/11/2006 (Fedaral Aviation Administration (FAA), 2008)

The purpose of the order is to "provide a doctrine for Federal Aviation Administration (FAA) Aviation Safety (AVS) services/offices to implement a common AVS Safety Management System (AVSSMS)". It cites SMS concepts such as the need for a more process-oriented system safety approach with an emphasis on management systems that ensure risk management, safety assurance and safety culture. The order requires each AVS service/office to develop and implement a plan for its functions under the AVSSMS, including the structure of its safety oversight relationship with the segment of industry for which it holds safety oversight responsibility (FAA Dept Transportation Order vs 8000.1, Sep 2006).

The order is applicable to individuals and entities over which AVS has safety oversight jurisdiction such as aviation product/service providers, which include "manufacturers, operators, maintainers, educators, providers of air traffic services, and others".

Par 2-4 refers to concepts related to aviation safety management and safety management systems evolving at the international level, and at the U.S. national level within the FAA. It notes that standards and principals that evolve from within the AVS organization will be aligned with national and international standards and concepts, and it invokes the requirement to align with Public Law 108-176, JDPO and the NGATS integrated plan.

Par 2-4.b. notes that ICAO has proposed a standard for member States that includes the requirement for each State to have a safety program to achieve an acceptable level of safety in the operation of aircraft, where the “acceptable level of safety” is to be defined by each State. And it notes that an element of the ICAO program as it relates to Annex 11, is for each State to require product/service providers to implement a State-approved SMS.

Section 3-1 requires that AVSSMS implement SMS in a fully integrated manner consistent with safety principals and concepts that serve as a model for international, national and agency policy. Integration must be accomplished across the organizational elements of AVS to ensure safety management throughout a product or service life cycle and in all areas of the aviation system, including:

a) <u>Design of aircraft and components</u>
b) <u>Manufacturer of aircraft and components</u>
c) Operation of aircraft
d) Maintenance of aircraft and components
e) Management of air traffic
f) Training and qualification of personnel
g) Maintenance of the aviation system infrastructure
h) Promulgation of standards through regulation and guidance materials

The above list is similar to ICAO’s SMS domain, and likewise includes aircraft manufacturers. As with ICAO, the FAA has defined SMS concepts, methodology, and implementation goals, but the details of an airframer SMS compliance model remain undefined.

## 2.10 FAA Order 8000.367; SMS Requirements

Ref. U.S. Department of Transportation FAA Order 8000.367; SUBJ: Aviation Safety (AVS) Safety Management System Requirements: Effective Date 05-14-2008 (FAA Department of Transportion, 05-14-2008).

This order full fills requirements described in FAA Order VS888.1, Safety Management System (SMS) Doctrine, Section 1-1.c (2). It provides requirements to be met by AVS services/offices to support AVSSMS. It is specific to aviation safety, does not address occupational safety and health or personnel safety issues, and does not address implementation schedules. It requires AVS services/offices to have processes and procedures in place to align with:

- SMS processes in other AVS services/offices
- AVSSMS
- SMS processes in product/service provider organizations for which the AVS service has oversight responsibility, if applicable.

The bulk of the order defines details of Safety Policy, Safety Risk Management, Safety Assurance and Safety Promotion such that the descriptions of these four components align directly with ICAO's SMM definitions.

As with other regulatory SMS publications, this order restates the philosophy and details of the globally accepted SMS model. But no specificity is given that defines details and data collection methods of how to implement an airframer or MRO SMS.

## 2.11 FAA Order 8000.368; Guidance for AFS Staff

Ref. U.S. Department of Transportation FAA Order 8000.368; SUBJ: Flight Standards Service Oversight: Effective Date 7/11/08 ("guidance for Flight Standards Service (AFS) staff and offices in meeting the requirements specified in FAA Order VS 8000.1, Safety Management System Doctrine") (FAA Department of Transportation, 7/11/08).

This order describes how the Flight Standards Service (AFS) complies with the Associate Administrator for Aviation Safety (AVS-1) Order VS 8000.1, Safety Management System Doctrine. The audience is principally AFS personnel who are responsible for safety and regulatory oversight of aviation certificate holders and service providers in the U.S as follows:

- Certification standards for air carriers, commercial operators, air agencies, and airmen (except air traffic control (ATC) tower operations)
- Flight procedures, operating methods, airmen qualification and proficiency, aircraft maintenance, and the maintenance aspects of continued airworthiness programs
- Service providers performing Instrument Flight Procedure (IFP) development, including flight inspection/flight validation services
- Registry of civil aircraft and all official airmen records, and supporting law enforcement agencies responsible for drug interdiction

Par 2.c.(2) invokes ICAO's standards and recommended practices "across the spectrum of international aviation activity and provides direction and guidance for member states". The Order also refers to ICAO's critical elements of a safety oversight system for oversight guidance – ICAO doc 9858 AN/474 (ICAO, Second Edition - 2011).

Although this order is specific to non-manufacturer oversight, the content becomes significant to an airframer's SMS development at the point where the airframer and aircraft operator SMSs intersect, i.e. with the aviation service interests of the manufacturer's business.

## 2.12 FAA SMS – Request for Comments

Ref. U.S. Federal Register / Vol.74, No 140 / Thursday, July 23, 2009 / Proposed Rules: Department of Transportation FAA [Docket No. FAA-2009-0671; Notice No 09-06]: SMS – Advanced Notice of proposed rulemaking (ANRPM), request for comments (USA Department of Transportation, Thursday, July 23, 2009).

The ANPRM solicits public comments on a potential rulemaking requiring “certain 14 CFR part 21, 119. 121, 125, 135, 141, 142, and 145 certificate holders, product manufacturers, applicants, and employers (hereafter ‘‘product/service providers’’) to develop a Safety Management System (SMS). SMS is a comprehensive, process-oriented approach to managing safety throughout an organization. An SMS includes an organization-wide safety policy, formal methods of identifying hazards, mitigating and continually assessing risk, and promotion of a safety culture. SMS stresses not only compliance with technical standards but increased emphasis on the organizational aspects and processes that ensure risk management and safety assurance.

The purpose for the ANPR is to give the aviation industry at large an opportunity to comment on issues and concerns they may have relative to the implementation of SMS. Responses were returned to the FAA by October 21, 2009.

At the time of this research, SMS remains at the stage of being understood from a legalistic/implementation standpoint, and no regulatory compliance model is defined for U.S. manufacturers or MROs – which leaves the field subjective for the definition of an airframer/manufacturing and MRO SMS implementation models.

## 2.13 FAA 14 CFR Part 5 – Safety Management Systems

Ref. Docket No. FAA–2009–0671; Notice No. 10–15; RIN 2120-AJ86. (FAA, 2009). In this NPRM the FAA defines the components of SMS as Safety Policy (subpart B), Safety Risk Management (subpart C), Safety Assurance (subpart D) and SMS Documentation and Recordkeeping (subpart F). The docket also provides descriptions of the elements that make up the components. These components and elements align directly with ICAO’s SMS architecture. Applicability is as follows:

(a) A certificate holder under part 119 of this chapter authorized to conduct operations in accordance with the requirements of part 121 of this chapter must have a Safety Management System that meets the requirements of this part and is acceptable to the Administrator by [date 3 years after the effective date of final rule].

(b) A certificate holder must submit an implementation plan to the FAA Administrator for approval no later than [date 6 months after the effective date of the final rule].

(c)The implementation plan may include any of the certificate holder's existing programs, policies, or procedures that it intends to use to meet the requirements of this part, including components of an existing SMS.

The docket proposed to require each certificate holder operating under 14 CFR Part 121 to develop and implement a safety management system (SMS) to improve the safety of its aviation-related activities. The proposal required the certificate holder to go beyond the basic regulations to minimize risk. The Airline Safety and Federal Aviation Administration Extension Act of 2010 required the FAA to conduct rulemaking to “require all Part 121 air carriers to implement a safety management system.”

The FAA also cited the International Civil Aviation Organization (ICAO), in its March 2006, amendments to Annex 6 part I, which addressed operation of airplanes in international commercial air transport, and established a standard for member states to mandate that each of these operators establish an SMS. The FAA argued that the need for SMS is in fulfillment of the international agreements. If adopted, the provisions in this rule would conform to these ICAO agreements.

The proposal stated that it is not the FAA's intent that this rule would result in contractors or subcontractors, or entities not directly regulated by the FAA, being required to develop an SMS. Existing processes required air carriers to ensure that the employees or businesses with whom they contract to conduct training or maintenance activities on their behalf are qualified, capable, and have the necessary equipment and facilities to perform the work. This proposal would not expand these existing requirements (Aircraft Electronics Association, 2010).

## 2.14 Transport Canada SMS

Ref. TP 13739 (04/2001), Introduction to Safety Management Systems (Transport Canada, 2001)

TP 13739 is an early SMS publication (2001) that introduces a Systems Approach to aviation safety management. The Forward states "…projected growth in aviation means that maintaining the current low accident rate will result in an unacceptable number of accidents. The challenge for Transport Canada and the industry is to find ways to lower the accident rate even further as the industry grows". TP13799 addresses a data-driven approach to enhancing aviation safety; using a risk-based approach to resource allocation to support those activities which will receive the greatest safety benefit; strengthening partnerships to put into effect the concept that responsibility for safety is shared by the regulator and the aviation community, implementing safety management systems in aviation organizations; taking account of human and organizational factors in safety management; and communicating effectively with the aviation community on safety. The material in the publication "is condensed from a number of sources to introduce safety management system principles and concepts", with special thanks to Civil Aviation Safety Authority of Australia (CASA).

TP 13739 does not refer to the four SMS components since those became established in subsequent years. However, while it contains no specific SMS airframer content, the material is valuable in understanding early roots and logic of SMS.

## 2.15 Regulations Amending CARS

Ref: Canada Gazette, Vol. 139, No 10 – March 5, 2005: Regulations Amending the Canadian Aviation Regulations (Parts I, IV, V and VII). (Canada Gazette, March 5th, 2005)

This publication is similar to the U.S. FAA's Request for Comments (July 23, 2009). It introduces, into the public domain, its proposed regulatory amendments of requirements for holders of certain CAR certificates to appoint "accountable executives" to institute safety management systems. It states that "the current proposals will be followed by requirements", and states that two new subparts within Part I will be created, i.e. Subpart 106 Accountable Executive and the conditions applicable to all accountable executive appointees; and Subpart 107 Safety Management System Requirements.

The Alternatives section of the publication states that these proposed Regulations Amending the CARS build upon the work of leading safety experts and international bodies, such as ICAO. It states that the consequences of not acknowledging the need to overhaul and modernize the framework would "leave Canadian civil aviation facing an increased risk of incidents and accidents", and that there is "no alternative to regulatory action that will accomplish the necessary changes".

The Consultation section provides a timeline history of developments that led to the proposed regulatory amendment including: "Starting with the meeting of the Maintenance and Manufacturing Technical Committee (Part V) in February 2000 at which the concept of "accountable executive" was introduced to the committee members, meetings of the Personnel Licensing and Training Technical Committee (Part IV), the Maintenance and Manufacturing Technical Committee and the Commercial Air Service Operations (CASO) Technical Committee (Part VII) were held over the period from 2000 to 2003. In addition, members of the General Technical Committee (Part I) were briefed on the status of the safety management system proposals at their meeting of October 22, 2002, and discussed the proposals for the introduction of requirements for accountable executives and for safety management systems at their meeting of April 3, 2003".

The General Provisions section contains definitions that affect accountable executives and specifies certificates that are impacted as defined in subsequent subparts 6 and 7:

## 2.16 CAR Part I – Subpart 6

Ref: Canadian Aviation Regulations (CAR) Part I - Subpart 6 – Accountable Executive. Content last revised: 2007/12/30 (Canadian Department of Transportation, 2007/12/30)

106.01 – Application

This subpart is applicable to the following certificates: An airport certificate issued under section 302.03: A flight training unit operator certificate issued under section 406.11: A manufacturer certificate issued under section 561.03:, and an approved maintenance organization (AMO) certificate issued under section 573.02

## 2.17 CAR Part I – Subpart 7

Ref: Canadian Aviation Regulations (CAR) Part I - Subpart 7 - Safety Management System Requirements. Content last revised 2007/12/30 (Transport Canada, 2001)

107.01 - Application

This subpart is applicable to an applicant for, or holder of an approved maintenance organization (AMO) certificate under CAR section 573.02: An air operator certificate under CAR section 705.07; An airport certificate under CAR section 302.03; and Air Traffic Services (ATS) operations certificates under CAR section 801.05 (air traffic control or flight service station).

107.02 - Establishing a Safety Management System

This subpart requires that the applicant or holder of a certificate referred to in section

107.01 shall “establish, maintain and adhere to a safety management system”.

107.03 – Safety Management System

This subpart defines the contents of an SMS as follows:

a) a safety policy on which the system is based;
b) a process for setting goals for the improvement of aviation safety and for measuring the attainment of those goals;
c) a process for identifying hazards to aviation safety and for evaluating and managing the associated risks;
d) a process for ensuring that personnel are trained and competent to perform their duties;
e) a process for the internal reporting and analyzing of hazards, incidents and accidents and for taking corrective actions to prevent their recurrence;
f) a document containing all safety management system processes and a process for making personnel aware of their responsibilities with respect to them;
g) a quality assurance program; (amended 2008/01/01;
h) a process for conducting periodic reviews or audits of the safety management system and reviews or audits, for cause, of the safety management system; and
i) any additional requirements for the safety management system that are prescribed under these Regulations.

107.04 – Size

This subpart states that the SMS “shall correspond to the size, nature and complexity of the operations, activities, hazards and risks associated with the operations of the holder of a certificate referred to in section 107.01”.

## 2.18 EASA's view on SMS

Ref: EASA's view on SMS: Approach to an integrated management system. The European Business Aviation Convention & Exhibition (EBACE), EBACE, Geneva 13th May 2009: Daniela Defossar / Rulemaking Directorate. (European Aviation Safety Agency (EASA), May 2009)

This presentation noted NPA 2008-22C in reference to proposed implementing rules on organization requirements for SMS. It is currently applicable to: Approved training organizations; Commercial operators: and non-commercial operators of complex motor-powered aircraft. In the future it will apply to Maintenance organizations, and design and production organizations.

It states that proposed acceptable means for SMS compliance are

a) Adapted to the size of organizations
b) Based on ICAO documentation
c) Safety policy
d) Safety risk management
e) Safety assurance
f) Organization and accountabilities
g) Training and communication on safety
h) Occurrence reporting scheme
i) Organization manual
j) Compliance monitoring system

## 2.19 UK CAA

As of 1st January 2009, the UK CAA encouraged Air Operators Certificate holders, Part-M subpart G organizations, and maintenance organizations to have an "SMS implementation plan that will provide a fully functional SMS in two to three years" (UK Civil Aviation Authority (CAA), 2008). The UK CAA refers to EASA for implementing rules, which in turn (as with other aviation bodies) contains the requirement for an ICAO-compliant SMS. Other documentation that UK CAA points to for SMS implementation includes: CAA

Safety Management Systems Guidance Material that is based on ICAO Document 9859; CAA Gap Analysis/Checklist that is available for an organisation to assist in constructing an implementation plan, or assess an existing SMS for compliance with elements and components of an SMS as shown in the CAA SMS Guidance Material; ICAO Document 9859 Safety Management Manual; ICAO SMS Training Material; and EASA Regulation 216/2008 - the basic regulation that requires a safety management system.

UK CAA does not currently encourage aircraft manufacturers to implement an SMS. However, ICAO does, so one would expect UK CAA to encourage airframers SMSs sometime in the future – just as other aviation administrators will most likely require airframers to have SMS in the longer term rather than the shorter term.

## 2.20 Regulatory Observation

The objective of the regulatory overview was to assess SMS advisories and regulations being developed and published, and determine their applicability to U.S. aircraft production and MROs. With so many state regulatory bodies, and so many domains and opinions it can be confusing to assimilate where SMS is, and who should do what. SMS has generally been a collective and shared effort with U.S. and non-U.S. aviation administrators and industry. It is recognized that ICAO defines the universally accepted SMS model with four key components: Safety Promotion, Safety Policy, Safety Risk Assessment, and Safety Assurance. These components contain constituent elements

But ICAO is not the founder of aviation SMS."It's incorrect to assume that SMS is an ICAO-driven initiative. While ICAO is coordinating worldwide SMS activity as the custodian of SMS standards and a focal point for SMS information, the FAA and a number of other aviation authorities started developing SMS well before ICAO issued its standards. As well as the U.S., several other countries were also exploring system safety oversight and SMS. So when the ICAO proposal for SMS standards came along, the United States and almost all other major states endorsed it. Some nations such as Canada and Singapore were ahead of the curve" [Don Arendt, FAA].

In 2008, even though the FAA agreed with ICAOs proposed SMS standards it was unable to complete the rulemaking in time for ICAO's implementation date of 2009 for commercial airlines, so it filed a “difference”, and continued to work toward SMS–based oversight. The FAA chartered an Aviation Rulemaking Committee (ARC) – and the ARC filed the responses and comments in its April 2010 report. At that time congressional action (HR 5900) required the FAA to mandate that all Part 121 operators implement an SMS. The FAA was given 90 days from when it was signed into law [Aug. 2, 2010] to produce an NPRM and two years to produce a final rule. Without congressional endorsement, the FAA cannot approve or accept anything that's not a regulation. Meanwhile EASA set an April 2012 target date for the rulemaking process. FAA AC120-92A (date) was published. It was the hoped-for document telling operators what they "have to do”, and AC120-9A (date) clarified the definition of an aviation service provider as "any organization providing aviation services."

So what does this all mean to the industry? It is accepted that the FAA plans to eventually to condense all safety practices into a single regulatory structure. Companies that have adopted a course of action to comply with international standards in order to operate outside the United States are taking a conservative approach, starting early, and in the absence of hard guidance

Regardless of where the aviation SMS drive started, it is clear that the era of SMS is upon us. It is aimed at every enterprise touching aviation, from manufacturers to aircraft operators, FBOs and maintenance shops. The most common complaint is that the approval process is unclear because the SMS concept as of 2010 was not embodied in regulation (Larson, 2010).

Aviation administrators first required some form of SMS with airline operators. MROs are next in line. Although U.S. aircraft manufacturers have received guidance, they have yet to receive specifically mandated regulations. However, given the global market that U.S airframers of large commercial jets serve, observations point to the fact that in the future, the FAA will become definitive with SMS aircraft production. With this, it may be prudent for U.S.-based manufacturers to adopt some form of SMS to align with overseas markets, or to show that their current QMS contains the equivalent elements of the ICAO SMS model.

# 3.0 Methodology

## 3.1 Introduction

The approach to accomplish this research is to align SMS industry and regulatory developments with field tests for the purpose of evaluating and or validating the practicality of SMS in the manufacturing and maintenance domains of the aviation industry. The researcher became involved in the development of SMS at the U.S. state level, and simultaneously worked in the aircraft production domain to observe how SMS may apply. The methodology used for field tests was based on development and experimental iterations of a process, revision of the process, and testing of revised processes until a quantifiable and repeatable practice was recognized.

## 3.2 JPDO membership

The U.S. Joint Planning and Development Office is a collaboration of networks that include members of the aviation community to participate in NextGen projects, activities, and initiatives. It provides an environment for the government and industry to share information and collaboratively engage in discussions and activities. As an active JPDO member from 2008 through 2010, the researcher supported the SMS development group that generated policy definition. By participating in this forum that met for four consecutive days each month in WADC, the researcher gathered first-hand data from members who represented commercial and military interests as SMS definition was developed, addressed implementation issues for the aviation industry at large, and coordinated with ICAO regarding ICAO’s SMS goals. Participation as a JPDO working-group member allowed the researcher to align SMS implementation research with the development of national and international SMS initiatives.

## 3.3 Review of SMS regulations (U.S. and global)

Upon beginning SMS research, a thorough review was undertaken of proposed national and international regulations, and industry responses. This review highlighted ICAO’s and the FAA’s drive to implement SMS into all domains of the aviation industry, and member state's recognition of SMS as defined by ICAO, i.e. the SMS "components" and "elements". The review also highlighted regulators' multi-year approach at mandating SMS into airlines, as opposed to just recommending SMS as an industry practice, and emphasized the question of how SMS may be applied to all aviation domains, i.e. the aircraft lifecycle – not just the airline domain.

## 3.4 Executive management charter / sponsorship

With the FAA moving SMS discussion into the aircraft production domain, executive managers at a large aircraft manufacturing company questioned how SMS may, or may not apply. The researcher gained sponsorship from said company to charter a team to explore the practicality of SMS implementation into the production environment. Throughout field tests of this study, the researcher reported back to the sponsors to provide results and maintain support. Reviews were not only essential to gain continued support, but from an ethical perspective, they also provided a forum to report out prospective production information discovered during research that may need attention. As shown by literature reviewed during this thesis, top management sponsorship is essential for SMS research and or implementation – it must be top down – it cannot be driven from the bottom up.

## 3.5 Production commodity and Integrated Product Team (IPT)

Regulators organize the airplane by Air Transport Association (ATA) "chapters". The chapters fall under three categories: Airframe Systems; Structure; and Power Plant. Airframe Systems consists of 30 ATA chapters, there are 7 chapters for Structure, and 16 chapters for Power Plant. These chapters are often referred to as "commodities" or "ATAs" by production operations. For example ATA 27 is the flight controls commodity (Airframe Systems), ATA 32 is the landing gear commodity (Airframe Systems), ATA 53 is the doors commodity (Structure), ATA 74 is the ignition commodity (Power Plant), and so forth [APPENDIX B]. Production companies typically have an IPT (or equivalent body) consisting of Subject Matter Experts (SME) organized around each commodity.

Due to the number of commodities and time availability, it was necessary for this research to select one representative commodity to investigate and thereby keep research scope to a manageable level. During discussions with executive sponsorship it was determined that the Fuel IPT (chapter 28) would support research. The FAA Part 25 production certificate requires that all production commodities are monitored with quantitative metrics (also referred to as datastreams) that are used to control the health of the production system. Based upon this production data, production operations managers continuously prioritize commodities for process review, organizational change, output reliability, and so forth. The Fuel commodity was selected since it was already prioritized.

## 3.6 IPT initiation

In the “kick-off” meeting the researcher initiated the Fuel commodity IPT with an overview of the executive charter and SMS. It was emphasized that the IPT was authorized to support research, but support was secondary to maintaining existing job roles and responsibilities. The researcher was cognizant that any actual or perceived perception that the research was negatively impacting existing personnel’s attention to current responsibilities, or production operations, may jeopardize the charter. Primary IPT members supporting research included the IPT leader, manufacturing engineer, quality engineer, industrial engineer, and a quality investigator. Additional on-call IPT staff/disciplines included:

- Design and operations support engineer
- Liaison engineer
- Design engineer
- Structures Engineer
- Risk analysis engineer
- Production supervisors
- Mechanics (preflight and flight test)

- Wings mechanic
- Project manager/administrator
- Supplier management
- Materials management
- Equipment Quality Analyst
- Human factors
- Airworthiness Representative (AR)

The initial meeting included an overview of the ICAO SMS components and elements. SMS was proposed as a prospective methodology to manage risk in the production environment, and ICAO's Risk Assessment Matrix and Risk Tolerability Matrix were presented as the target format for quantifying risk.

## 3.7 Workshops and production process walk data

The researcher proposed to the IPT that the study take place through a series of workshops. Workshop meetings brought the IPT together to collectively discuss approaches to experiment with SMS in the production environment, assess possible data-gathering tools already available and or customize them, create new data gathering formats if and as necessary, conduct iterative and revised field tests, and appraise results. Over the course of more than a year, the meetings typically took place on a bi-weekly basis.

In this paper the term "process walk" is used to describe the event of staff - usually engineers and associated professionals associated with a specific commodity – of "walking" the production line and talking with production mechanics to understand how well (or not) aspects of the build process, or IP are, and if and how improvements can be made. The researcher concurred with the IPT that process walks would be key to gathering human factors information to support production input into a broader SMS-like risk model.

The researcher considered the use of the Gemba methodology to support production process walks. "The Gemba Walk is all about getting out into the workplace. It affords company leaders, managers and supervisors a reliable, simple and easy means of supporting an improvement structure and encouraging process standardization. The Gemba Walk is a key component in the sustainment of improvement" (The LEANing Post, 2010). However, the researcher and IPT determined that while applicable for general process information, questions formulated and quantified by the commodity-specific IPT would be time-efficient and appropriately focussed – as was evidenced in Field Test 3 - when talking with mechanics during process walks. Therefore Gemba Walks were not used.

The researcher also considered the Maintenance Error and Decision Aid (MEDA) tool as a format for collecting process walk data. MEDA is a structured process for investigating the causes of errors made by aircraft maintenance technicians and inspectors. It is an organization's means to learn from its mistakes. Errors are a result of contributing factors in the workplace, most of which are under management control. (William Rankin, 2007). However, MEDA is a reactive investigation process that although aircraft-specific, is not commodity-specific. And similar to Gemba Walks it was determined that proactive questions generated by the IPT would best support research. Thus the MEDA tool was also deselected.

## 3.8 Data assimilation

The researcher considered various formats for collecting and correlating process walk data into risk information that would support ICAO's risk assessment and tolerability matrixes. The Failure Mode Effects Analysis (FMEA) model was selected. It is also referred to as potential failure modes and effects analysis; failure modes, effects and criticality analysis (FMECA) ..... is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service ..... is prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones" (Tague, 2004). Furthermore, the first step in the FMEA process is to "assemble a cross-functional team of people with diverse knowledge about the process, product or service and customer needs. Functions often included are: design, manufacturing, quality, testing, reliability, maintenance, purchasing (and suppliers)". All these characteristics fit with the IPT already in place, so FMEA was selected as the format with which to gather data, including process walk observations, and prospectively feed results into an ICAO risk assessment and tolerability model.

## 3.9 Field tests and evaluation

Using FMEA as the general data collector, the researcher first attempted to link the three aviation domains of engineering, production, and flight operations into a single SMS risk assessment architecture. Multiple field tests were undertaken with various fuel systems production installation plans, and as data was evaluated, the architecture transitioned to a production-centric only model that became defined as "PRMS", rather than "SMS". This paper describes three of the field tests, to highlight how and why the details of the architecture transitioned. Several process walks and FMEA evaluations were undertaken. Field tests 1, 2 and 3 represent key milestones as experimentation of a production-like SMS transitioned into what became known as "PRMS".

## 3.10 Review of industry progress

With a PRMS model developed, further academic and industry literature review was conducted to benchmark research findings with current industry developments. Some arguments were found in support of research conclusions, and overall the industry continues to move at varying stages towards SMS, or SMS-like agendas.

# 4.0 Field Tests

## 4.1 Introduction

SMS requires a standard repeatable process to proactively gather and assess data, and subsequently disposition the results using risk probability values to determine prospective mitigative actions. This research explores the feasibility of a single SMS data model for the entire airplane lifecycle. Can a “Mitigate Production Risk” step be incorporated to support a holistic SMS that fully integrates aircraft engineering/manufacturing, airline, and maintenance operations? Should SMS remain specific to airline operations, and a similar but separate “SMS” data architecture be deployed the other domains? If separate, how or should domain-specific SMSs be connected? [Figure 4-1].

Airline SMS’s are designed to gather, assess and disposition data to identify single points of failure that can propagate into systemic risks in the airline operating domain. An example would be low hydraulic fluid pressure due to a mechanic’s error (single point of failure) causing an operational-economic risk in terms of the landing gear not retracting after takeoff, and an air turnback that incurs passenger travel delays (systemic risks). Or, the A&P’s error may cause the gear not to deploy upon landing thus resulting in an operational-safety risk.

At the discretion of the airline, various methodologies that align with regulatory oversight are used to proactively gather data that can indicate a prospective failure point. The ICAO SMS model requires the data to be quantified with a risk probability value (L). The possible (or known) impact of the failure point at the systemic level is evaluated with a risk severity value (S), and the allowance of the risk to remain in the system (or be mitigated out) is reviewed through the lens of a tolerability matrix. This research conducted field tests to explore the feasibility of creating a Risk Tolerability Matrix that is not constrained to one domain, but is architected to connect some or all of the airplane lifecycle domains.

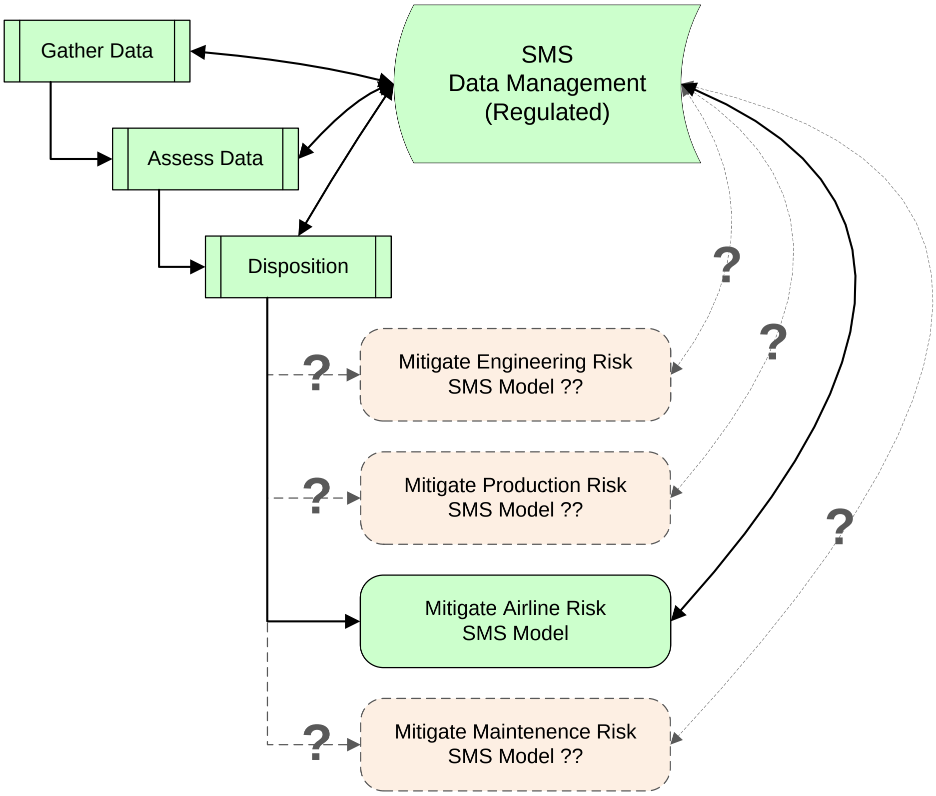



**Figure 4-1. Airplane Lifecycle SMS Data Management**

## 4.2 Quantification of risk

SMS is defined as "*A dynamic risk management system based on quality management system (QMS) principles in a structure scaled appropriately to the operational risk, applied in a safety culture environment*". (Stolzer, et al., 2008).

FAA and ICAO guidance define SMS risk as a measure of the expected losses that can be caused by an undesired event, factored with the probability of that event occurring, or, risk equals Likelihood x Severity (Stolzer, et al., 2008):

$$R = L \times S$$

For example, in the context of the low hydraulic fluid pressure causing aircraft landing gear retraction failure, L accounts for the airline mechanic's erroneous accomplishment of the Task Card. Task cards include specific maintenance steps as defined and controlled by the quality system, that are performed in order for the Certificate of Airworthiness to remain current with the aircraft. L represents the single point of failure of a task card (undesired event). And “S” represents the negative systemic impact, that is, airline operational safety risk.

Comparable to airline maintenance task cards, the aircraft factory uses Installation Plans (IP). Manufacturing planners and quality engineers write IPs with process steps that mechanics accomplish to build aircraft. An IP error can be a single point of failure on the production line that can negatively manifest downstream in the production system, or once the airplane has left the factory and is in-service with the airline.

This research is central to identifying the “L” and “S” values within the production system, and explores the possibility of connecting the resulting Risk (R) value to a holistic aircraft lifecycle SMS. Field Tests use data from the Engineering, Production and Airline domains.

## 4.3 Field Test 1: EPA

### 4.3.1 Engineering, Production and Airline Data

Field Test 1 gathered data from Engineering (E), Production (P) and Airline (A) domains. The objective was to test whether a link existed across the domains, and establish if it was possible to *directly* correlate an airline risk event to an upstream IP production occurrence, and from production further upstream to design/engineering.

SMS requires a risk probability value (L), but it is the enterprise’s discretion to determine a process for assimilating data to generate it. To support the processes of identifying, assessing and dispositioning, a Failure Mode and Effects Analysis (FMEA) matrix was selected to integrate data from the E, P and A domains. FMEA was one of the first systematic techniques for failure analysis. It was developed by reliability engineers in the 1950s to study problems that might arise from malfunctions of military systems. In later decades versions became used in many industries (Dhillon, 1990). FMEA involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, causes and effects. FMEAs provide single point inductive reasoning root cause analysis, based on knowledge and experience with products and processes – key to SMS' proactive and predictive philosophy. FMEAs are widely used in development and manufacturing industries at various phases of the product life cycle (Xiao, et al., 2011). And FMEAs are formatted to structure mitigation based on risk intelligence gathering – also compatible with SMS.

IP "XYZ" from the fuel systems aircraft production line was selected as a test case. The objective was to gather information of how the IP was accomplished by talking directly with the mechanics. Although IPs specify steps that must be completed and bought-off, there can be some variance as to how the steps are completed subject to the specific mechanic doing the task, and how the environment and human factors can influence completion of the task. The 13 production steps for IP XYZ were listed in the EPA FMEA. Then, with input from the mechanics that perform the IP, potential failure modes, causes and effects for each IP task prospective failure scenario were recorded in the matrix. To quantify the relevance of each IP task failure scenario, values were entered into the corresponding E and P columns. The ExP value was recorded as the FMEA engineering/production Risk Priority Number (RPN), which correlated to ICAO's "L" value, and "L" was then reviewed relative to the Airline (A) value to quantify the systemic airline risk in the context of ICAO's "S' value [Figure 4-2].

| **Instl Plan XYZ** | | **Field Test 1: EPA Failure Modes and Effects Analysis** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **IP Step** | **Task** | **POTENTIAL FAILURE MODE** | **POTENTIAL CAUSES** | **POTENTIAL EFFECTS** | **DETECTION METHOD** | **E** | **P** | ***RPN (E*P)*** | **A** |
| **1.** | **Receive Inlet** | inlet not received | unavailable | no inlet installed | Visual Inspection | 1 | 1 | 1 | 4 |
| **2.** | **Remove Plastic Wrapping** | plastic wrapping in tank | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | Visual Inspection, Fuctional test | 1 | 2 | 2 | 3 |
| **3.** | **Removal of end caps** | end caps left in fuel tank (FOD) | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | Visual Inspection, Fuctional test | 1 | 2 | 2 | 3 |
| **4.** | **Clean mating surface** | mating surfaces not cleaned/prep | forgetting to prep | bad seal - fuel transfer | Visual Inspection | 1 | 3 | 3 | 3 |

**Figure 4-2. Portion of EPA FMEA**

Values for the Engineering "E" input were selected from a scale of 1 to 10 based upon component/system reliability subject to engineering design statistics [Figure 4-3]. Values for the Production "P" input were selected from a scale of 1 to 10, based upon the probability of not detecting the production error subject to the existing QMS process attached to the IP task step [Figure 4-4]. And the Airline "A" input value was selected, also on a scale of 1 to 10, based upon the impact the IP error may have on the airline, if the error was not detected by the production enterprise [Figure 4-5].

| E Input for EPA FMEA | | |
|---|---|---|
| **E** = Component / system reliability based on **Engineering** design statistics | **Reliability Values** | **INPUT** |
| Very High: Failure is almost inevitable | > 1 in 2 | **10** |
| | 1 in 3 | **9** |
| High: Repeated failures | 1 in 8 | **8** |
| | 1 in 20 | **7** |
| Moderate: Occasional failures | 1 in 80 | **6** |
| | 1 in 400 | **5** |
| | 1 in 2,000 | **4** |
| Low : Relatively few failures | 1 in 15,000 | **3** |
| | 1 in 150,000 | **2** |
| Remote: Failure is unlikely | < 1 in 1,500,000 | **1** |

**Figure 4-3. E Input for EPA FMEA**

| P Input for EPA FMEA | |
|---|---|
| **P** = Probability of not detecting **Production** error based on QMS process | **INPUT** |
| Manufacturing Self Inspection | 10 |
| | 9 |
| Quality Shakedow n type inspection | 8 |
| | 7 |
| Installation verification performed at end of specificied task | 6 |
| | 5 |
| Installation verified via 100% concurrent inspection | 4 |
| | 3 |
| Installation are verified via sampling surviellance and corrective action systems | 2 |
| | 1 |

**Figure 4-4. P Input for EPA FMEA**

| A Input for EPA FMEA | | |
|---|---|---|
| **A = Airplane** risk based on operational statisitics | **Risk definition** | **INPUT** |
| Hazardous without warning | Very high severity ranking when a potential failure mode effects safe system operation<br>and/or non-compliance with government regulation without warning. | 10 |
| Hazardous with warning | Very high severity ranking when a potential failure mode affects safe system operation<br>and/or non-compliance with government regulation with warning. | 9 |
| Very High | Loss of primary function.<br>- System inoperable with destructive failure without compromising safety | 8 |
| High | Reduction of primary function.<br>- System inoperable with equipment damage | 7 |
| Moderate | Loss of comfort/convenience function.<br>- System inoperable with minor damage | 6 |
| Low | Reduction of comfort/convenience function.<br>- System inoperable without damage | 5 |
| Very Low | Returnable appearance and/or noise issue noticed by most customers.<br>- System operable with significant degradation of performance | 4 |
| Minor | Non-returnable appearance and/or noise issue noticed by customers.<br>- System operable with some degradation of performance | 3 |
| Very Minor | Non-returnable appearance and/or noise issue rarely noticed by customers.<br>- System operable with minimal interference | 2 |
| None | No discernable effect. | 1 |

**Figure 4-5. A Input for EPA FMEA**

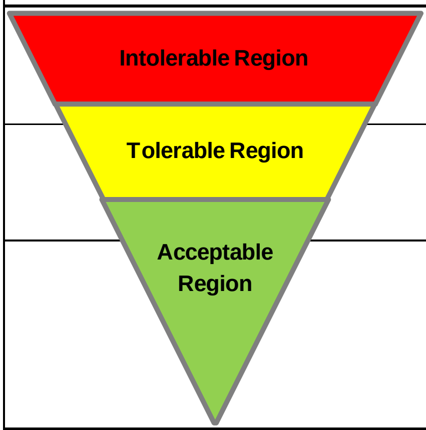
### 4.3.2 Risk Assessment and Tolerability Matrices

ICAO SMS uses a Risk Assessment Matrix to quantify risk probability (L) and risk severity (S) [Figure 4-6]. L correlates to the FMEA RPN, and S correlates to the FMEA A value. These translate to Risk Assessment values of 1A through 5A on the ICAO scale. ICAO then uses a Risk Tolerability Matrix to quantify results [Figure 4-7]. The values were then entered into the EPA FMEA for assessment [Figure 4-8].

| Field Test 1: EPA Risk Assessment Matrix | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***(L) Engr & Prod'n Risk Probability*** **L = f (E, P)** | | | ***(S) Risk severity*** *Risk to in-service aircraft if enginering and or production errors manifest* | | | | |
| RPN conversion to ICAO scale | | | "A" input conversion to ICAO scale | | | | |
| FMEA RPN (E*P) | Value (L) | Meaning | A = 9 to 10<br>Catastophic A | A = 7 to 8<br>Hazardous B | A = 3 to 6<br>Major C | A = 2<br>Minor D | A = 1<br>Negligable E |
| 91 to 100 | 5 | Frequent | 5A | 5B | 5C | 5D | 5E |
| 51 to 90 | 4 | Occasional | 4A | 4B | 4C | 4D | 4E |
| 21 to 50 | 3 | Remote | 3A | 3B | 3C | 3D | 3E |
| 11 to 20 | 2 | Improbable | 2A | 2B | 2C | 2D | 2E |
| 1 to 10 | 1 | Extremely Impossible | 1A | 1B | 1C | 1D | 1E |

**Figure 4-6. Field Test 1: Risk Assessment Matrix**

**ICAO Risk Tolerability Matrix**




| | | |
|---|---|---|
| Intolerable Region | 5A, 5B, 5C<br>4A, 4B, 3A | Unacceptable under the existing circumstances |
| Tolerable Region | 5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C | Acceptable based on risk mitigation. It may require management decision |
| Acceptable Region | 3E, 2D, 2E, 1A, 1B, 1C, 1D, 1E | Acceptable |

**Figure 4-7. ICAO Risk Tolerability Matrix**

**L** = Engr & Prod'n IP Risk: Values from "E-P-A Risk Assessment Matrix".

**S** = Engr & Prod'n to Airline Systemic Impact: Values from "E-P-A Risk Assessment Matrix".

**E** = Engineering component reliability statistics (*Occurrence*). Values from "E Input for EPA FMEA".

**P** = IP Production Error Likelihood based on QMS (*Detectability*). Values from "P Input for EPA FMEA".

**A** = Airplane in-service failure probability statisics (*Severity* if IP error escapes). Values from "A Input for EPA FMEA".

| Instl Plan XYZ | Field Test 1: EPA Failure Modes and Effects Analysis | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **IP Step** | **Task** | **POTENTIAL FAILURE MODE** | **POTENTIAL CAUSES** | **POTENTIAL EFFECTS** | **E** | **P** | ***RPN (E*P)*** | **A** | ***L*** | ***S*** | ***Tol*** |
| **1.** | **Receive Inlet** | inlet not received | unavailable | no inlet installed | 1 | 1 | 1 | 4 | 1 | 1C | A |
| **2.** | **Remove Plastic Wrapping** | plastic wrapping in tank | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 3 | 1 | 1C | A |
| **3.** | **Removal of end caps** | end caps left in fuel tank (FOD) | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 3 | 1 | 1C | A |
| **4.** | **Clean mating surface** | mating surfaces not cleaned/prep | forgetting to prep | bad seal - fuel transfer | 1 | 3 | 3 | 3 | 1 | 1C | A |
| | | | wrong solvent | bad seal - fuel transfer | 2 | 3 | 6 | 3 | 1 | 1C | A |
| **5.** | **Ok to seal** | missed inspection | mechanic doesn't stop for QA | bad seal - fuel transfer | 1 | 1 | 1 | 3 | 1 | 1C | A |
| | | | interrupted work | bad seal - fuel transfer | 5 | 1 | 5 | 3 | 1 | 1C | A |
| | | contamination on mating surfaces after buyoff | job sequencing | bad seal - fuel transfer | 4 | 3 | 12 | 3 | 2 | 2C | T |
| **6.** | **apply sealant** | wrong type of seal | wrong sealant used | bad seal - fuel transfer | 4 | 5 | 20 | 3 | 2 | 2C | T |
| | | imcomplete application of seal | not enough sealant | bad seal - fuel transfer | 1 | 1 | 1 | 3 | 1 | 1C | A |
| **7.** | **install inlet** | installed clocked | no mistake proofing | fuel pickup | 1 | 1 | 1 | 3 | 1 | 1C | A |
| | | seal cured prior to install | job sequencing, interrupted work | rework or bad seal - fuel transfer | 5 | 1 | 5 | 3 | 1 | 1C | A |
| | | wrong torque sequence | didn't know requirement | bad seal - fuel transfer | 1 | 1 | 1 | 3 | 1 | 1C | A |
| **8.** | **inspection - verify seal** | missed inspection | interrupted work | can't continue work | 6 | 1 | 6 | 1 | 1 | 1E | A |
| | | roller stamping | schedule | bad seal - fuel transfer | 6 | 10 | 60 | 3 | 4 | 4C | T |
| **9.** | **remove excessive seal** | don't remove excess seal | forgot | no effect | 1 | 10 | 10 | 1 | 1 | 1E | A |
| **10.** | **start tube installation with** | jumper bond missing | tube installed without jumper bond. | High static discharge - Ignition sources | 1 | 1 | 1 | 10 | 1 | 1A | A |
| **11.** | **clean mating surfaces** | no cleaning | work interruption | high resistance, compromised bond | 2 | 2 | 4 | 5 | 1 | 1C | A |
| **12.** | **attach jumper to inlet clamp** | loose fastening | under torque | bond jumper detach - static discharge | 6 | 2 | 12 | 10 | 2 | 2A | T |
| | | clamp installed at an angle | torqued during installation | compromised bond | 5 | 2 | 10 | 5 | 1 | 1C | A |
| | | wrong hardware used | mixed parts | compromised bond, corrosion | 1 | 10 | 10 | 5 | 1 | 1C | A |
| **13.** | **perform resistance** | missed operation | work interruption | rework, improper ground may lead to | 1 | 1 | 1 | 10 | 1 | 1A | A |
| | | meter out of calibration | defective equipment | compromised bond | 4 | 7 | 28 | 5 | 3 | 3C | T |
| | | accepted out of spec value | work interruption | compromised bond | 1 | 1 | 1 | 5 | 1 | 1C | A |
| | | incorrect testing | Training/experience | failed resistence test, rework then retest | 4 | 1 | 4 | 2 | 1 | 1D | A |

**Figure 4-8. Field Test 1: EPA FMEA**

### 4.3.3 Field Test 1 Assessment

Field Test 1 experimented with ICAO's format for assessing risk severity. A single data point from each of the engineering, production and airline domains was connected in the context of the aircraft lifecycle, and correlated to an ICAO-style SMS risk tolerability value. However, in practicality, a single data point is not inclusive of all aspects of the QMS in each domain system, and therefore a single data point does not indicate whether or not a risk can escape to the downstream domain. The EPA model documented the value of "A" in the context of the IP error escaping to the airline. But the single-point model does not take into account the many steps within the production system after accomplishment of the IP that could or would detect and correct the IP error before escaping.

Furthermore, the type of risk that is under review needs to be better understood. Risk to the production domain means production risk. The primary business of manufacturing is to build aircraft, and to better understand risk for this domain in the context of an ICAO risk assessment, the model must better quantify the production system. And a risk to the production system does not necessarily correlate to an aircraft operational safety risk that is the focus of airline SMS. It is important to note that personnel safety risk, and culture, is a supporting (not primary) function of both the aircraft production and airline domains. The primary function of airlines is to fly airplanes safely for the public – and thus *Safety*MS. SMS *operational safety* is not to be confused with the supporting function of airline mechanics, for example, whose *personal safety* is part of the culture, or painters on the aircraft production line who use safety tethers for protection them should they accidently fall from a gantry.

Field Test 1 suggests that while data from the aircraft lifecycle can in theory be collected and collaborated into an ICAO risk assessment matrix, in practicality challenges are realized with aligning the *primary* domain-specific risk types, and with developing a comprehensive model that includes all the QMS functions that are already in place with each domain.

## 4.4 Field Test 2: OPA

In light of observations from Field Test 1, Field Test 2 distinguished the need for greater focus on the production system – specifically to quantify the actual reported count of IP errors. IP errors are leading indicators of production system health. So the focus became to further consider the production-to-airline connection and mock-up this interface, and see if an IP error can *directly* correlate to an airline risk in the context of ICAO's SMS Risk Assessment Matrix. For simulation the engineering domain was excluded, and the FMEA model was revised to receive two production domain inputs, and one airline domain input.

### 4.4.1 Production and Airline Data

The same IP was used as in Field Test 1, and the FMEA tasks, potential failure modes, potential causes and potential effects as identified with process walks with the mechanics remained unchanged. However, to provide better production focus, the FMEA was revised to OPA [Figure 4-9].

The "E" input from Field Test 1 was replaced with "O" to represent the Occurrence (or count) of production Non-Conformance Reports (NCR) – also referred to as "rejection tags" [**Error! Reference source not found.**]. The "P" input remained, however the input table was revised from a scale of 1 to 10, to a scale of 1 to 5 to better align with ICAO's risk assessment matrix that is on a 1 to 5 scale [**Error! Reference source not found.**]. Similarly, the "A" input remained but was revised to a 1 to 5 scale based on TC categories of in-service risk, thus improving the clarity of definitions [Figure 4-12].

| Instl Plan XYZ | | Field Test 2: OPA Failure Modes and Effects Analysis | | | | | | |
|---|---|---|---|---|---|---|---|---|
| IP Step | Task | POTENTIAL FAILURE MODE | POTENTIAL CAUSES | POTENTIAL EFFECTS | O | P | *RPN (O*P)* | A |
| 1. | Receive Inlet | inlet not received | unavailable | no inlet installed | 1 | 1 | 1 | 3 |
| 2. | Remove Plastic Wrapping | plastic w rapping in tank | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 2 |
| 3. | Removal of end caps | end caps left in fuel tank (FOD) | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 2 |
| 4. | Clean mating surface | mating surfaces not cleaned/prep | forgetting to prep | bad seal - fuel transfer | 1 | 2 | 2 | 2 |

**Figure 4-9. Portion of OPA FMEA**

| O Input for OPA FMEA | | |
|---|---|---|
| O = Occurrence | **Occurrence** (count) of production Non-Conformance Reports (NCR) | INPUT |
| Very High (Chronic) | 37 - 60 (~5 per month) | 5 |
| High (Repeated) | 13 - 36 (~3 per month) | 4 |
| Moderate (Occasional) | 7 - 12 (~1 per month) | 3 |
| Low (Relatively few) | 2 - 6 (~1 per 2 months) | 2 |
| Remote (Zero to rare) | 0 - 1 (~ 0 per year) | 1 |

**Figure 4-10. O Input for OPA FMEA**

| P Input for OPA FMEA | | |
|---|---|---|
| **P** = Probability of not detecting **Production** error based verification method | **Quality Verification methods as applied to IP and task cards** | **INPUT** |
| Absolute Uncertainty | Manufacturing Self Inspection | 5 |
| Low | Quality Shakedown type inspection | 4 |
| Moderate | Installation verification performed at end of specified | 3 |
| High | Installation is verified via 100% concurrent inspection | 2 |
| Almost Certain | Installations are verified via sampling surveillance & corrective action systems | 1 |

**Figure 4-11. P Input for OPA FMEA**

| A Input for OPA FMEA | | |
|---|---|---|
| **A** = Severity of operational **Airplane** risk | **Risk definition** | **INPUT** |
| Catastrophe (Category 1) | Failure conditions which would prevent continued safe flight and landing. | 5 |
| Hazard (Category 2) | Failure conditions which would reduce the capability of the airplane functions, safety margins, and operation efficiencies such as:<br>1) Physical distress or higher workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely<br>2) Serious or fatal injury to a relatively small number of the occupants. | 4 |
| Major (Category 3) | Failure conditions which would reduce the capability of the airplane functions, safety margins, and operation efficiencies. i.e. Adverse operating conditions. | 3 |
| Minor (Category 4) | Failure conditions which would not significantly reduce airplane safety which involve crew actions that are well within their capabilities. | 2 |
| None (Category 5) | No discernable effect. | 1 |

**Figure 4-12. A Input for OPA FMEA**

## 4.4.2 Risk Assessment and Tolerability Matrices

FMEA results were translated to the OPA Risk Assessment Matrix to obtain "L" and "S" values [Figure 4-13], and the corresponding 1A through 5A values were input back to the OPA FMEA [Figure 4-14]. ICAO's Risk Tolerability Matrix was again used (unaltered) to assign tolerability values [Figure 4-7].

| **Field Test 2: OPA Risk Assessment Matrix** | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***(L) Production Risk Probability*** **L = f (O, P)** | | | ***(S) Risk severity*** *Risk to in-service aircraft if production errors manifest* | | | | |
| RPN conversion to ICAO scale | | | "A" input conversion to ICAO scale | | | | |
| FMEA RPN (O*P) | Value (L) | Meaning | A = 5<br>Catastophic<br>A | A = 4<br>Hazardous<br>B | A = 3<br>Major<br>C | A = 2<br>Minor<br>D | A = 1<br>Negligable<br>E |
| 21 to 25 | 5 | Frequent | 5A | 5B | 5C | 5D | 5E |
| 16 to 20 | 4 | Occasional | 4A | 4B | 4C | 4D | 4E |
| 11 to 15 | 3 | Remote | 3A | 3B | 3C | 3D | 3E |
| 6 to 10 | 2 | Improbable | 2A | 2B | 2C | 2D | 2E |
| 1 to 5 | 1 | Extremely Impossible | 1A | 1B | 1C | 1D | 1E |

**Figure 4-13. Field Test 2: Risk Assessment Matrix**

**L** = Production-to-production IP Risk. Values from "O-P-A Risk Assessment Matrix".

**S** = Manufacturer-Airline Systemic Impact. Values from "O-P-A Risk Assessment Matrix".

**O** = Count of production NCRs (*Occurrence*). Values from "O Input for OPA FMEA".

**P** = IP Production Error Likelihood based on QMS (*Detectability*). Values from "P Input for OPA FMEA".

**A** = Airplane in-service failure probability statisics (*Severity*). Values from "A Input for FMEA".

| Instl Plan XYZ | Field Test 2: OPA Failure Modes and Effects Analysis | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **IP Step** | **Task** | **POTENTIAL FAILURE MODE** | **POTENTIAL CAUSES** | **POTENTIAL EFFECTS** | **O** | **P** | ***RPN (O*P)*** | **A** | ***L*** | ***S*** | ***Tol*** |
| 1. | Receive Inlet | inlet not received | unavailable | no inlet installed | 1 | 1 | 1 | 3 | 1 | 1C | A |
| 2. | Remove Plastic Wrapping | plastic wrapping in tank | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 2 | 1 | 1D | A |
| 3. | Removal of end caps | end caps left in fuel tank (FOD) | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 2 | 1 | 1D | A |
| 4. | Clean mating surface | mating surfaces not cleaned/prep | forgetting to prep | bad seal - fuel transfer | 1 | 2 | 2 | 2 | 1 | 1D | A |
| | | | wrong solvent | bad seal - fuel transfer | 2 | 2 | 4 | 2 | 1 | 1D | A |
| 5. | Ok to seal | missed inspection | mechanic doesn't stop for QA | bad seal - fuel transfer | 1 | 1 | 1 | 2 | 1 | 1D | A |
| | | | interrupted work | bad seal - fuel transfer | 3 | 1 | 3 | 2 | 1 | 1D | A |
| | | contamination on mating surfaces after buyoff | job sequencing | bad seal - fuel transfer | 3 | 2 | 6 | 2 | 2 | 2D | A |
| 6. | apply sealant | wrong type of seal | wrong sealant used | bad seal - fuel transfer | 3 | 3 | 9 | 2 | 2 | 2D | A |
| | | imcomplete application of seal | not enough sealant | bad seal - fuel transfer | 1 | 1 | 1 | 2 | 1 | 1D | A |
| 7. | install inlet | installed clocked | no mistake proofing | fuel pickup | 1 | 1 | 1 | 2 | 1 | 1D | A |
| | | seal cured prior to install | job sequencing, interrupted work | rework or bad seal - fuel transfer | 3 | 1 | 3 | 2 | 1 | 1D | A |
| | | wrong torque sequence | didn't know requirement | bad seal - fuel transfer | 1 | 1 | 1 | 2 | 1 | 1D | A |
| 8. | inspection - verify seal | missed inspection | interrupted work | can't continue work | 4 | 1 | 4 | 1 | 1 | 1E | A |
| | | roller stamping | schedule | bad seal - fuel transfer | 3 | 5 | 15 | 2 | 3 | 3D | T |
| 9. | remove excessive seal | don't remove excess seal | forgot | no effect | 1 | 5 | 5 | 1 | 1 | 1E | A |
| 10. | start tube installation with | jumper bond missing | tube installed without jumper bond. | High static discharge - Ignition sources | 1 | 1 | 1 | 5 | 1 | 1A | A |
| 11. | clean mating surfaces | no cleaning | work interruption | high resistance, compromised bond | 2 | 2 | 4 | 3 | 1 | 1C | A |
| 12. | attach jumper to inlet clamp | loose fastening | under torque | bond jumper detach - static discharge | 3 | 2 | 6 | 5 | 2 | 2A | T |
| | | clamp installed at an angle | torqued during installation | compromised bond | 3 | 2 | 6 | 3 | 2 | 2C | T |
| | | wrong hardware used | mixed parts | compromised bond, corrosion | 1 | 5 | 5 | 3 | 1 | 1C | A |
| 13. | perform resistance | missed operation | work interruption | rework, improper ground may lead to ignition | 1 | 1 | 1 | 5 | 1 | 1A | A |
| | | meter out of calibration | defective equipment | compromised bond | 3 | 4 | 12 | 3 | 3 | 3C | T |
| | | accepted out of spec value | work interruption | compromised bond | 1 | 1 | 1 | 3 | 1 | 1C | A |
| | | incorrect testing | Training/experience | failed resistence test, rework then retest | 3 | 1 | 3 | 2 | 1 | 1D | A |

**Figure 4-14. Field Test 2: OPA FMEA**

### 4.4.3 Field Test 2 Assessment

Field Test 2 experimented with the production-to-airline link using ICAO's SMS Risk Assessment Matrix. The inclusion of NCRs provided improved production resolution (compared to Field Test 1), but the two production data points still did not comprehensively represent the production QMS filters that are in place to catch IP escapements within the production system. And the "A" value of the IP error escaping to the airline did not take into account the airline QMS filters that would or could catch the error and mitigate it at some point.

Field test 2 defined a risk - but not the *type* of risk, i.e. production or safety. For example, an IP escapement can become an economic inconvenience and or schedule disruption to downstream production if rework is required, but this does not imply an airline safety risk. As with Field Test 1, Field Test 2 suggests that while data from aircraft lifecycle domains can in theory be collected and collaborated into an ICAO risk assessment matrix, in practicality challenges are realized with aligning the *primary* domain-specific risk types, and with developing a comprehensive model that includes all the QMS functions that are already in place with each domain.

## 4.5 Field Test 3: OD

Field Test 3 focussed on applying the SMS Risk Assessment Matrix exclusively to the production domain. Attention focussed on the same fuel systems IP as in the previous field tests. But the Airline (A) value was replaced with a Production Escapement (PE) value to measure of how far down the production system a prospective IP error may travel (or escape) before becoming known (or manifesting).

### 4.5.1 Production Data

FMEA tasks, potential failure modes, potential causes and potential effects as identified in the previous field tests were unchanged. However, to focus entirely on production, the FMEA was revised to OD [Figure 4-15].

In Field Test 2 the “O” input recorded the NCR count associated with the IP task, or step. However, NCRs are key and very visible metrics that are already carefully watched within the production system as a function of the QMS. In SMS language NCRs can be classified as “leading indicators” that identify areas for proactive attention (Lofquist, 2010). Indeed, it was a higher than average fuel systems NCR count that pointed this research to IP XYZ. SMS philosophy requires awareness of human factors as part of the Assess-Disposition-Mitigate chain [Figure 4-1]. So “O” was revised to quantify the likelihood of an IP error based specifically on human factors information gathered from the shop floor.

To generate the “O” FMEA input, 10 questions were established that focussed on the risk of IP accomplishment subject to human factors. The questions were answered by mechanics accomplishing the IP. Based upon their number of “yes” or “no” responses, the Occurrence value translated to a scale of 1 to 5 for input to the FMEA [Figure 4-16].

In Field Test 2 the “P” input was based upon the probability of not detecting the production error subject to the existing QMS process attached to the IP task step. For Field Test 3, “P” was replaced by “D”. This represented the Detectability of an IP issue, and included 10 questions that were answered by Quality and Manufacturing Engineers from the dedicated Fuel Systems IPT. As with the “O” input, based upon their number of “yes” or “no” responses, the “D” value was translated to a scale of 1 to 5 for input to the FMEA [Figure 4-17].

In the context of ICAO SMS definition these values aligned directly with L = OxD, or Likelihood of Risk = Occurrence x Detectability.

| Instl Plan XYZ | | Field Test 3: OD Failure Modes and Effects Analysis | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **IP Step** | **Task** | **POTENTIAL FAILURE MODE** | **POTENTIAL CAUSES** | **POTENTIAL EFFECTS** | **O** | **D** | ***RPN (O*D)*** | **PE** |
| **1.** | **Receive Inlet** | inlet not received | unavailable | no inlet installed | 1 | 1 | 1 | 1 |
| **2.** | **Remove Plastic Wrapping** | plastic wrapping in tank | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 3 |
| **3.** | **Removal of end caps** | end caps left in fuel tank (FOD) | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 3 |
| **4.** | **Clean mating surface** | mating surfaces not cleaned/prep | forgetting to prep | bad seal - fuel transfer | 1 | 2 | 2 | 3 |

**Figure 4-15. Portion of OD FMEA**

| **O Input for OD FMEA** | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Is this a blind Installation<br>*Tip: Mechanic is installing by feel only, no visual* | y/n | | | | |
| 2 | Are the drawing / PDD requirements unclear<br>*Tip: Include shop practices, tribal knowledge, drawing and IP conflicts, etc* | y/n | | | | |
| 3 | Are there access issues<br>*Tip: Design complicates access* | y/n | | | | |
| 4 | Are there ergonomics / Human Factors / Industrial Safety or Accessibility issues?<br>*Tip: Examples include sizing range, position, weight and location of work, lighting, time before fatigue of position, etc.)* | y/n | | | | |
| 5 | Are there tooling issues?<br>*Tip: Inadequate space for tool application (tool sweep - greater than 60 degrees desirable), tool certification, etc.* | y/n | | | | |
| 6 | Is this a complex installation / design?<br>*Tip: Is the installation not mistake-proof?* | y/n | | | | |
| 7 | Are there follow-on related process steps?<br>*Tip: Safety device installation, sequencing of specific steps, etc.* | y/n | | | | |
| 8 | Is there a possibility that the job is split between shifts/mechanics?<br>*Tip: Non-Conformance Report?* | y/n | | | | |
| 9 | Is special training/certification required? | y/n | | | | |
| 10 | Are there additional contributing factors to potential occurrence?<br>*Tip: Dust, temperature, drilling, congested work area, etc.* | y/n | | | | |
| Occurrence (<=) | | 10% | 81% | 90% | 96% | 99% |
| Number of "yeses" to IP step | | >=5 | 4 | 3 | 2 | 1 |
| **O Input OD FMEA** | | **5** | **4** | **3** | **2** | **1** |

**Figure 4-16. O Input for OD FMEA**

| D Input for OD FMEA | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Would a failure of this process step physically prevent a subsequent operation?<br>*Tip: Failure substantially changes standard work procedures* | y/n | | | | |
| 2 | Is the process step part of a surveillance plan? (random witness of a process)<br>*Tip: Process Monitoring, Product and Process Surveillance (PPS* | y/n | | | | |
| 3 | Is there a witness inspection that would detect this potential failure mode? (Concurrent inspection, two sets of eyes)<br>*Tip: Watching actual process (Torque, Functional Test, etc.)* | y/n | | | | |
| 4 | Is there an in-process test or measurement that would detect a failure of this process step?<br>*Ex. Volt meter, go-no-go gages, functional test instrumentation*<br>*Tip: Detection method can be in a follow-on Installation plan.* | y/n | | | | |
| 5 | Does this process step require post process inspection?<br>*Tip: Application of Seal, grease* | y/n | | | | |
| 6 | Is the process step part of a sampling plan? (end-item inspection sampled)<br>*Tip: Lot Sampling Plans* | y/n | | | | |
| 7 | Would the potential failure mode result in a visible difference to the hardware or documentation?<br>*Tip: Can the process be visually inspected?* | y/n | | | | |
| 8 | Would a failure of this process step be detected at end-item verification? Job<br>*Tip: Job Sampling Surveillance System (JSSS)?* | y/n | | | | |
| 9 | Is the process step only manufacturing self examined? | y/n | | | | |
| | Detectability (<=) | 10% | 81% | 90% | 96% | 99% |
| | Number of "yeses" to IP step | 5y | 4y | 3y | 2y | 1y |
| | **D Input** | **5** | **4** | **3** | **2** | **1** |

**Figure 4-17. D Input for OD FMEA**

## 4.5.2 Risk Assessment and Tolerability Matrices

FMEA results were translated to the OD Risk Assessment Matrix to obtain “L” and “S” values [Figure 4-18], and the corresponding 1A through 5A values were input back to the OD FMEA [Figure 4-19]. ICAO’s Risk Tolerability Matrix was again used (unaltered) to assign tolerability values [Figure 4-7].

| Field Test 3: OD Risk Assessment Matrix | | | | | | | |
|---|---|---|---|---|---|---|---|
| **(L) IP Risk Probability**<br>**L = f (O, D)** | | | **(S) Production Risk Severity**<br>*Risk to production system subject to where IP error manifests* | | | | |
| RPN conversion to ICAO scale | | | "PE" input conversion to ICAO scale | | | | |
| FMEA RPN (O*D) | Value (L) | Meaning | PE = 5<br>Airline In-Service<br>A | PE = 4<br>Testflight / Pre-Delivery<br>B | PE = 3<br>Preflight<br>C | PE = 2<br>Downstream Prod'n Line<br>D | PE = 1<br>Immediate Prod'n Line<br>E |
| 15 to 25 | 5 | Frequent | 5A | 5B | 5C | 5D | 5E |
| 12 to 14 | 4 | Occasional | 4A | 4B | 4C | 4D | 4E |
| 9 to 11 | 3 | Remote | 3A | 3B | 3C | 3D | 3E |
| 6 to 8 | 2 | Improbable | 2A | 2B | 2C | 2D | 2E |
| 1 to 5 | 1 | Extremely Impossible | 1A | 1B | 1C | 1D | 1E |

**Figure 4-18. Field Test 3: Risk Assessment Matrix**

**O** = Occurrence of possible IP errors errors based on Human Factors. Values from "O Input for OD FMEA".
**D** = Detectability of possible IP errors based on QMS inspectio criteria. Values from "D Input for OD FMEA".
**PE** = Production Escapement: Values from "Production Escapement (PE) Input for OD FMEA".
**L** = Production single-point failure IP Risk. Values from "OD Risk Assessment Matrix".
**S** = Production Risk systemic impact. Values from "OD Risk Assessment Matrix".

| Instl Plan XYZ | | Field Test 3: OD Failure Modes and Effects Analysis | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **IP Step** | **Task** | **POTENTIAL FAILURE MODE** | **POTENTIAL CAUSES** | **POTENTIAL EFFECTS** | **O** | **D** | ***RPN (O*D)*** | **PE** | ***L*** | ***S*** | ***Tol*** |
| **1.** | **Receive Inlet** | inlet not received | unavailable | no inlet installed | 1 | 1 | 1 | 1 | 1 | 1E | A |
| **2.** | **Remove Plastic Wrapping** | plastic wrapping in tank | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 3 | 1 | 1C | A |
| **3.** | **Removal of end caps** | end caps left in fuel tank (FOD) | Left on as protection then forgot to remove | plugs the inlet screen - reduced/no fuel flow | 1 | 2 | 2 | 3 | 1 | 1C | A |
| **4.** | **Clean mating surface** | mating surfaces not cleaned/prep | forgetting to prep | bad seal - fuel transfer | 1 | 2 | 2 | 3 | 1 | 1C | A |
| | | | wrong solvent | bad seal - fuel transfer | 2 | 2 | 4 | 3 | 1 | 1C | A |
| **5.** | **Ok to seal** | missed inspection | mechanic doesn't stop for QA | bad seal - fuel transfer | 1 | 1 | 1 | 3 | 1 | 1C | A |
| | | | interrupted work | bad seal - fuel transfer | 3 | 1 | 3 | 3 | 1 | 1C | A |
| | | contamination on mating surfaces after buyoff | job sequencing | bad seal - fuel transfer | 3 | 2 | 6 | 3 | 2 | 2C | T |
| **6.** | **apply sealant** | wrong type of seal | wrong sealant used | bad seal - fuel transfer | 3 | 3 | 9 | 3 | 3 | 3C | T |
| | | imcomplete application of seal | not enough sealant | bad seal - fuel transfer | 1 | 1 | 1 | 3 | 1 | 1C | A |
| **7.** | **install inlet** | installed clocked | no mistake proofing | fuel pickup | 1 | 1 | 1 | 3 | 1 | 1C | A |
| | | seal cured prior to install | job sequencing, interrupted work | rework or bad seal - fuel transfer | 3 | 1 | 3 | 3 | 1 | 1C | A |
| | | wrong torque sequence | didn't know requirement | bad seal - fuel transfer | 1 | 1 | 1 | 3 | 1 | 1C | A |
| **8.** | **inspection - verify seal** | missed inspection | interrupted work | can't continue work | 4 | 1 | 4 | 1 | 1 | 1E | A |
| | | roller stamping | schedule | bad seal - fuel transfer | 3 | 5 | 15 | 3 | 5 | 5C | I |
| **9.** | **remove excessive seal** | don't remove excess seal | forgot | no effect | 1 | 5 | 5 | 3 | 1 | 1C | A |
| **10.** | **start tube installation with attached jumper bond** | jumper bond missing | tube installed without jumper bond. | High static discharge - Ignition sources | 1 | 1 | 1 | 4 | 1 | 1B | A |
| **11.** | **clean mating surfaces (clamp, inlet,** | no cleaning | work interruption | high resistance, compromised bond | 2 | 2 | 4 | 2 | 1 | 1D | A |
| **12.** | **attach jumper to inlet clamp** | loose fastening | under torque | bond jumper detach - static discharge | 3 | 2 | 6 | 3 | 2 | 2C | T |
| | | clamp installed at an angle | torqued during installation | compromised bond | 3 | 2 | 6 | 3 | 2 | 2C | T |
| | | wrong hardware used | mixed parts | compromised bond, corrosion | 1 | 5 | 5 | 1 | 1 | 1E | A |
| **13.** | **perform resistance check** | missed operation | work interruption | rework, improper ground may lead to ignition | 1 | 1 | 1 | 1 | 1 | 1E | A |
| | | meter out of calibration | defective equipment | compromised bond | 3 | 4 | 12 | 1 | 4 | 4E | T |
| | | accepted out of spec value | work interruption | compromised bond | 1 | 1 | 1 | 2 | 1 | 1D | A |
| | | incorrect testing | Training/experience | failed resistence test, rework then retest | 3 | 1 | 3 | 2 | 1 | 1D | A |

**Figure 4-19. Field Test 3: OD FMEA**

### 4.5.3 Field Test 3 Assessment

Field Test 3 experimented with production-to-production links using ICAO's SMS Risk Assessment Matrix. The production-centric ATA-specific model included human factors inputs that influenced the evaluation of the IP risk assessment. It weighed the IP risk in terms of PE severity to the production system. Unlike attempting to connect more than one domain, the application of the risk matrix for a single domain proved to be viable, and furthermore it focused on the risk that is primary to the domain. In the case of the production domain, *production* risk is measured by the ICAO Risk Assessment Matrix, and the *production* risk allowance level is categorized by the ICAO Risk Tolerability Matrix.

## 4.6 Evaluation of Field Tests

The three field tests each targeted the application of ICAO's risk assessment matrix. The first two tests applied the matrix to one or more domains, and it was observed that the matrix did not clearly identify a single point of failure as a function of multiple domains. The third test focussed on one domain – production – and was able to successfully apply the risk model to quantify a single point of production risk based upon IP input, and the systemic severity to the production system as a function of an IP error.

In observing the three field tests the outcome is apparent by comparing tolerability results [Figure 4-20]. The EPA FMEA that included all three domains yielded 20 Acceptable, 5 Tolerable and 0 Intolerable results for IP XYZ tasks. The OPA FMEA that did not include the engineering domain, and had a 2/3 to 1/3 focus on the production to airline domain yielded 4 Tolerable results and the remainder were Acceptable. The OD FMEA that was 100% production-centric yielded 19 Acceptable, 5 Tolerable, and 1 Intolerable result. This indicates that a multi-domain model is not data-concentrated to a degree that can focus on a single risk point. However, the model as applied to a single domain, ATA-specific commodity can focus on a single point, and assess its systemic impact within that domain. This research contends that SMS, as arguably proven with airlines, is viable based on this one-domain observation.

Another key aspect of Field Test 3 was the inclusion of human factors for the "O" input. In response to a leading indicator, such as a high NCR count, production enterprises often carry out a process walk – or Gemba Walk - of the shop floor to observe related activities. In Quality Management, a Gemba walk is defined as "the idea is that if a problem occurs, the engineers must go there to understand the full impact of the problem, gathering data from all sources. Unlike focus groups and surveys, Gemba visits are not scripted or bound by what one wants to ask". (Imai, 1997)

Field tests did experiment with Gemba Walks but found the unscripted nature to be too undefined to provide a consistent and repeatable focus on IP human factors. Therefore the IPT generated the "O" questions, and walked the floor and asked the mechanics for "yes" or "no" responses that aligned with the context of human factors – a key constituent of SMS intent.

The field tests constitute the Risk Management and Risk Assurance components of the ICAO SMS model. Observations substantiate that these two components, in an SMS-like architecture, can be applied to the production domain. However, the outcome is Production Risk Management – not Safety Risk Management. With this it is suggested that as applied to production the model should be referred to as a Production Risk Management System (PRMS).

In the context of ICAO's L and S:

***Production Risk (PR) = L x S***

L = IP Risk Probability

= Likelihood of IP error at production line

L = O x D

O = Likelihood of Occurrence of IP error

D = Likelihood of Detecting IP error at production line

S = IP Risk Severity

= Severity of IP escapement: How far along the production line, and into the airline, the IP error can travel (escape) before becoming known (manifesting).

Furthermore, it is important to note that field tests were carried out using one ATA commodity – Fuel. There are 30 Airframe System chapters, and 7 Structure chapters. Field tests developed a method for quantifying a risk Assessment and Risk Tolerability matrix in the Fuel system commodity. For the PRMS model to be successful across the entire aircraft manufacturing domain, the IPT assigned to each commodity must develop their ATA-specific “O” and “D” questions to support an ATA-specific Risk Assessment Matrix. To generate an overarching production domain risk management view, all the resulting risk assessment matrixes need to be correlated – possibly by simply multiplying them together. These would then feed an overarching manufacturer’s PR tolerability matrix.

| | | **Field Test 1** Engr, production & airline data | | | **Field Test 2** Production and airline data | | | **Field Test 3** Production data only | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Instl Plan: XYZ** | | **EPA FMEA** | | | **OPA FMEA** | | | **OD FMEA** | | |
| **IP Step** | **Task** | ***L*** | ***S*** | ***Tol*** | ***L*** | ***S*** | ***Tol*** | ***L*** | ***S*** | ***Tol*** |
| 1. | Receive Inlet | 1 | 1C | A | 1 | 1C | A | 1 | 1E | A |
| 2. | Remove Plastic Wrapping | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| 3. | Removal of end caps | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| 4. | Clean mating surface | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| | | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| 5. | Ok to seal | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| | | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| | | 2 | 2C | T | 2 | 2D | A | 2 | 2C | T |
| 6. | apply sealant | 2 | 2C | T | 2 | 2D | A | 3 | 3C | T |
| | | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| 7. | install inlet | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| | | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| | | 1 | 1C | A | 1 | 1D | A | 1 | 1C | A |
| 8. | inspection - verify seal squeeze out | 1 | 1E | A | 1 | 1E | A | 1 | 1E | A |
| | | 4 | 4C | T | 3 | 3D | T | 5 | 5C | I |
| 9. | remove excessive seal | 1 | 1E | A | 1 | 1E | A | 1 | 1C | A |
| 10. | start tube installation with attached jumper bond | 1 | 1A | A | 1 | 1A | A | 1 | 1B | A |
| 11. | clean mating surfaces (clamp, inlet, jumper, washer) | 1 | 1C | A | 1 | 1C | A | 1 | 1D | A |
| 12. | attach jumper to inlet clamp | 2 | 2A | T | 2 | 2A | T | 2 | 2C | T |
| | | 1 | 1C | A | 2 | 2C | T | 2 | 2C | T |
| | | 1 | 1C | A | 1 | 1C | A | 1 | 1E | A |
| 13. | perform resistance check | 1 | 1A | A | 1 | 1A | A | 1 | 1E | A |
| | | 3 | 3C | T | 3 | 3C | T | 4 | 4E | T |
| | | 1 | 1C | A | 1 | 1C | A | 1 | 1D | A |
| | | 1 | 1D | A | 1 | 1D | A | 1 | 1D | A |

**Figure 4-20. Comparison of Field Test Results**

# 5.0 ICAO and Production Risk Management System (PRMS) Model

With Field Tests substantiating PR as the key output of "SMS" architecture when applied to the production domain, ICAO's model is revisited and recomposed in the context of a PRMS. ICAO identifies SMS via 4 components [Figure 2-2]. These support the implementation and functionality of SMS and have become the accepted standard with the aviation industry and regulatory bodies internationally. By adopting the same architecture, translating it into the production domain and integrating IP Risk Probability (L) as defined by Field Tests, PRMS emerges with the concept that PRMS can connect (via external escapements) to airline SMSs, but while the systems are similar they are not the same. SMS supports airlines' safety risk. PRMS supports manufacturers' production risk.

The term "risk management" has been defined by ICAO as "the identification, analysis and elimination (and/or mitigation to an acceptable or tolerable level) of those hazards, as well as the subsequent risks, that threaten the viability of an organization" (ICAO, 2009). Another "risk management" definition is "the overall process of identifying, evaluating, controlling or reducing, and accepting risk. It is the general term given to the process of making management decisions about risks that have been identified and analyzed" (Wells & Rodrigues, 2003). It is important to note that these definitions define "risk" regardless of the domain. Field tests show that the *type of risk* is domain-centric – and therefore production risk and safety risk must be quantified and managed according to the applicable domain.

This paper now refers to Bill Yantis' "SMS Implementation" (Stolzer, et al., 2011), and converts key aspects of his ICAO SMS implementation strategy into a PRMS implementation framework: PRMS parallels SMS by defining *production* as the state in which PR is reduced to, and maintained at or below, an acceptable level through a continual process of risk identification and risk management. This includes a closed loop system of measurement and evaluation of production rate goals and operations, organizational performance, and human factors as set by the aircraft manufacturing enterprise.

PRMS is holistic. No single action or person causes a PR. Risk is a result of an infinite number of related events that align to cause the perfect storm (Reason, 1991). PRMS, as with SMS, is a system that seeks to proactively predict and mitigate – or head off - this perfect storm. But it is not absolute:

- In the perfect world PR would be entirely eliminated, but absolute control is unachievable with human beings and dynamic production operations.
- PR is an integral and unavoidable aspect of aircraft manufacturing.
- PR is the outcome of the management of manufacturing processes.
- PRMS should be considered as an optional business advantage strategy, even though some form of “SMS” for aircraft production and maintenance is likely to become a future regulatory requirement.

PRMS defines the *acceptable and measurable level of PR margin*. PRMS focuses on correlating IP risks with metrics from sources including non-conformance reports, internal escapements, external escapements, supply issues, production rate goals, personnel training and qualifications, and human factors. PR is already central to production QMSs, and aligning them into the PRMS architecture would require investment for development and implementation – an investment similar to that of airlines aligning aircraft flight operations QMSs with SMS architecture. By the same argument this research suggests that by organizing around the components and elements as transcribed to PRMS, aircraft manufacturing companies would add to the integrity of already excellent QMSs. “very frankly, it’s matter of education. Once people see the advantages, they will be more likely to establish an “SMS” program in the absence of regulation (Overhaul & Maintenance (OVMT), 2009). As transcribed from ICAO’s SMS, PRMS includes 4 Components [Figure 5-1].

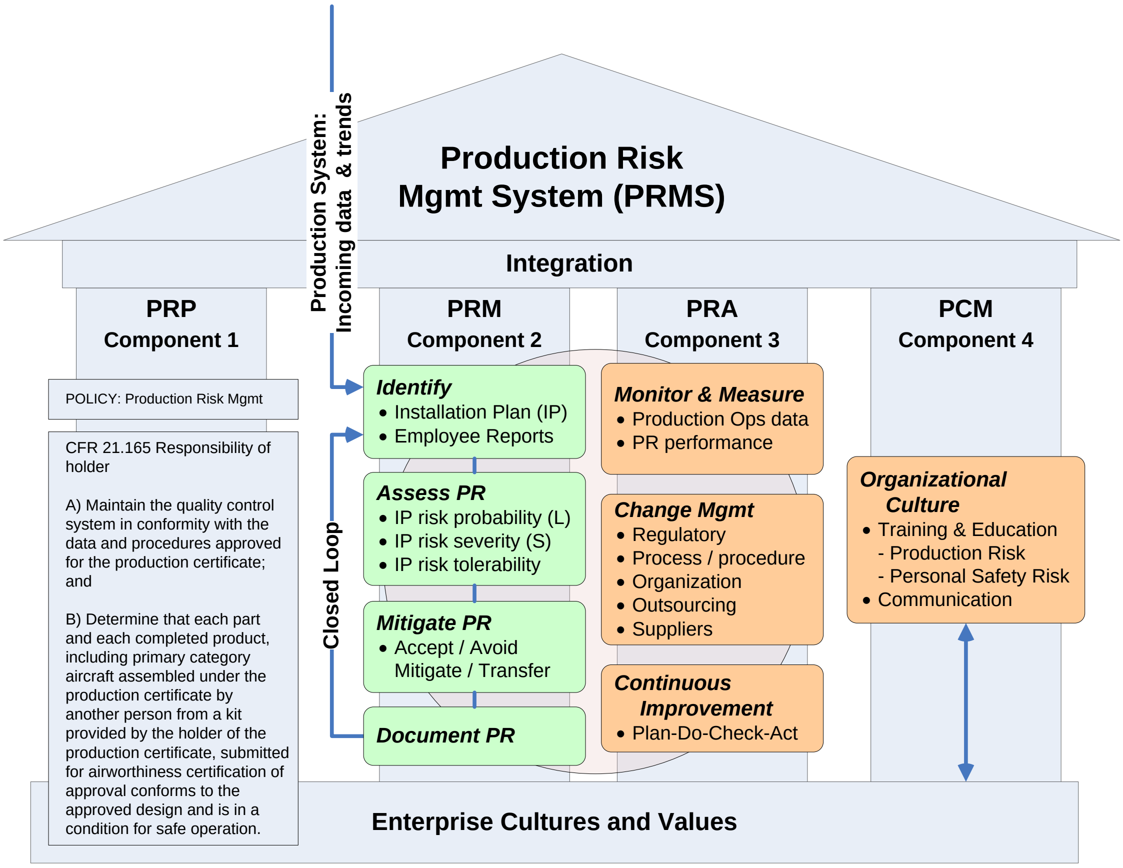



**Figure 5-1. PRMS Architecture**

Of the four components, the risk management and risk assurance components require the most tailoring when transitioning from SMS to PRMS. Although both SMS and PRMS follow the Identify-Assess-Mitigate chain, the risk management and risk assurance components require significant alteration to encompass specific production nuances. The culture and policy components require less alteration since they are based on many industry studies and regarding organizational management, and therefore much of the language is transferable not only from SMS, but from other general sources.

## 5.1 Component 1: Production Risk Policy

### 5.1.1 Element 1 – Management commitment and responsibility

Management commitment and responsibility: Commitment of senior management to PR is reflected in a policy statement signed by the accountable executive.

*Accountable Executive*

Just as ICAO SMS requires commitment from executive management, and as with nuclear regulators' observation of the need for executive accountability, PRMS needs support at the top enterprise level. Such commitment includes the identification of an Accountable Executive with overall responsibility for PR. This person would have authority for policy decisions, provision of resources, financial control, and PR reviews. The PRMS Accountable Executive would enforce essential tenets:

- PRMS is *the business approach* to managing production risk.
- PR indices (including ICAO's risk assessment matrix and risk tolerability matrix) and mitigation as primary PRMS functions.
- At time of implementation PRMS is a cultural change.
- Production line supervisors and employees hold PR accountability, and senior management provides full support.
- The enterprise ensures a healthy production culture with non-punitive action regarding human error management.

*PR Policy*

The enterprise PR policy must unequivocally show, via auditable documentation, senior management's commitment to PR as central to the aircraft production enterprise. Management must create and maintain a healthy production culture whereby employees feel comfortable to do the right thing, and as appropriate report and query a standard production process that appears to be problematic. Through such reporting not only is the prospective risk averted, but the process is revised to mitigate risk out of the production line.

*PR Reporting*

Similar to SMS safety policy, PR policy ensures a non-punitive PR reporting process. Traditionally, management reviewed confidential reports without the reportee identifying oneself. However, such confidentiality may not provide a feedback loop for management to gain additional information and make production line improvements. Organizations may prefer such reporting because it may shield adverse information from regulators during an investigation. In recognition of this issue the FAA implemented the optional non-punitive Aviation Safety Action Program (ASAP) for airlines that incentivise employees who provide safety information. Similarly, PRMS can seek a regulated manufacturers' PR reporting process to positively recognize employees who provide PR information.

*PR Review Board*

Similar to SMS's accountable executive, the PRMS accountable executive should own and lead the PR review board – typically a weekly or monthly assessment meeting to review production performance metrics including:

- results of PR assessments
- results of production operations audits, inspections and investigations
- human factors
- operations feedback
- regulatory violations, and proposed and upcoming regulatory changes
- process initiatives and organizational conformity
- status of PR items in mitigation

### 5.1.2 Element 2 – Production accountabilities

A statement of accountabilities clearly defines production responsibilities of managers and employees at different levels in the organization with effective delegation of responsibilities established for operationally critical areas when principal office holders are absent.

As with all regulated industries, job roles and responsibilities are clearly spelled out in aircraft manufacturing enterprises. Definitions are defined with RAAs -

Responsibility, Accountability, and Authority (RAA). A minimal number of additional RAAs should be necessary for PRMS implementation, such as Accountable Executive and PRMS manager, but most positions within production RAAs already include, or can be adjusted to encompass.

- Responsibility: The specific job function, duty or task assigned to each production employee along with necessary resources to perform the operational duties, as aligned with the work processes, procedures and activities. For example, the responsibility of IP XYZ installation is assigned to a fuel systems installation mechanic as defined by his RAA.
- Accountability: Responsibility defines the *physical activity* of performing the job, and accountability is the *obligation* of the mechanic to meet the results of work activities.
- Authority: The power or ability to command, grant permission and or approve is defined by individuals' authorities. Authority is delegated by management to enable an individual to complete an activity such as the IP. Or a mechanic may be delegated authority to sign off an IP on behalf of the QMS inspector.

### 5.1.3 Element 3 – Appointment of key production personnel

The production manager is tasked by the accountable executive with the daily oversight functions of PRMS. Depending on the PRMS-QMS implementation strategy, the PRMS accountable executive may assign daily responsibility to the PRMS or QMS manager. Since aircraft manufacturing companies are typically large well-organized enterprises, this paper suggests that existing production and QMS personnel, i.e. those who formed the IPT for the Field Tests, are suited to manage and perform the functionalities to support PRA and PRM.

*Selection Process and Criteria*

Selection and implementation of PRMS staff parallels dialogue that, since the inception of SMS, has been pivotal. As with successful businesses, margins are monitored closely, and additional expenditures must be carefully scrutinized. PRMS is a production versus protection discussion that is about risk management in the universal sense. When so many layers of protection applied such that at the cost of protection exceeds the value of the product? Or such that the cost crosses the threshold of diminishing returns? To paraphrase James Reason: “production risk is defined more by its absence than its presence” (Reason, 1991). To put a value on measuring “absence” may seem intangible so the PRMS manager must be versed with all aspects of PRMS including the investment discussion. He must command strong managerial skills to effectively communicate with top leadership, as well as manage technical issues to ensure PRMS functionality.

*Professional Training*

For PRMS consistency, specific training should be established. Many technical managers have limited formal training in areas such as systems management, organizational behaviour, production risk, QMS and human factors (Stolzer, et al., 2011). As with many training requirements under a Part 25 certificate, PRMS training should be established and recurrent.

### 5.1.4 Element 4 – Coordination of emergency PR response planning

An Emergency Response Plan (ERP) includes contingency plans to ensure proper response to executive management decision-makers when a critical production risk situation arises. For example, if an installation continues to be problematic to the point where an imminent production stoppage may, or has occurred, key decision-makers must have 24/7 visibility of such an event in order to deploy emergency resources, or take appropriate action, to avert the production line stoppage.

### 5.1.5 Element 5 - PRMS documentation

PRMS documentation: All production management activities must be documented and be available to all employees.

Regulated enterprises require a documentation system that defines company operating policies and procedures. PRMS must align with the existing with organizational structures that are typically in place with large enterprises, that is a convention of four tiers: Organizational, divisional, departmental, and the task level. This ensures that all management and staff have defined and auditable definitions of their respective areas.

## 5.2 Component 2: Production Risk Management

PRMS requires that the organization has a formal means to collect, analyze and apply results from three different types of data (Johnson, 2012):

- Reactive: The event has already occurred. Depending on the severity of the event it will become known through the "grapevine" or if highly critical it may make the morning news. Companies usually already have accident/event procedures in place and have investigative processes to establish fact-finding contributing factors. The event investigation process is a reaction to the event – and thus the term "reactive"
- Proactive: Collecting, analyzing and assessing data is not new. But he emphasis on the term "proactive" is new. Production organizations have auditing, quality and safety departments that assess production performance and risk. The company is responsible for collecting and assessing opportunities for improvement with the data – and in PRMS (as with SMS) such audits are referred to as "proactive".
- Predictive: Predictive data systems are a means to use daily/normal operations to help identify production strengths and weaknesses. This data helps identify the hazards and threats so they can be managed before they become errors, or before an IP error escapes into the production stream. It is a matter of identifying and addressing challenges as early as possible. In advance of assigning a risk level. Frontline employees often see hazards and threats before management therefore predictive data should be worker-cantered. Voluntary reporting systems are effective and are addressed in the Production Culture Management component.

PRM houses the Identify-Assess-Mitigate-Document chain. It is about using leading indicators such as NCR counts to identify an IP for proactive assessment. But PR does not exclusively deal with sub-optimal IPs. It is also about identifying areas of personal safety risks and hazards that can undermine the efficiency (or risk) of a production system.

### 5.2.1 Element 6 – Aircraft Production hazard identification

The manufacturer must maintain processes that insure that hazards are identified for all operational activities. Hazard identification is based on a combination of reactive, proactive and predictive production management methods.

*Production Hazard Definition*

ICAO identifies hazards in the context of an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function (ICAO, 2009).

With PRMS a production hazard is considered as a situation with the potential to cause injuries to production personnel, damage to production facilities, equipment or structures, loss of material, damage to the aircraft, or any damage that would negatively affect production rates and or generate production escapements. By paralleling ICAO’s context into production, PRMS adopts three categories of hazard – natural, technical and economic:

Natural Hazards are consequence of the environment within which production operations take place such as movement of the aircraft as it moves from the assembly line to field test, flight test, and equipment exposed to the weather outside production facilities:

- Severe weather (i.e. thunderstorms, floods, lightening, and hurricanes)
- Adverse weather (i.e. icing, heavy rain and snow)
- Geophysical events (i.e. earthquakes and floods)
- Environmental (i.e. wildlife and wildfires)
- Public health (i.e. sickness and epidemics)

Technical Hazards are the result of malfunctions in equipment, software or sources of energy:

- Production systems (i.e. tooling, machinery, computing and data infrastructure)
- Organization's facilities (i.e. offices, production hangars, flight line)
- Systems and equipment external to the organization (i.e. partners and, suppliers)

Economic hazards are the consequence of the global socio-political economic environment in which the manufacturing company operates in:

- Global GDP (i.e. multiple enterprise suppliers and partners in multiple global locations, operating in an integrated global economy)
- Recession (i.e. 2008 financial crisis)
- Production costs (material, equipment, people)

*Production Hazard Sources*

Manufacturing organizations are continuously exposed to production hazards. PRM begins with the identification of these hazards through the formal process of collecting, recording, analyzing and providing feedback to assigned production managers. Four types are data are available to the manufacturer – external, corporate, functional and individual. Data from these sources supports the IPT (as defined in field tests) before beginning an IP process walk.

- External sources: The oversight of Production Certificates by regulators such as the FAA in the United States, CAA in the United Kingdom, CASA in Australia, and JCAB in Japan. Regulators maintain compliance-based surveillance by deploying onsite inspectors at the manufacturing facilities. This traditional approach works in conjunction with production QMSs data collection, and supports proactive hazard identification.
- Corporate or organizational source: As the safety services department for SMS provides independent analysis of risk data, the production QMS department collects production data on behalf of the PRMS accountable

executive. Production hazards or threats are identified during the review of employee reports and annual or bi-annual audit data.

- Functional source: PRMS audits take place intermittently during the calendar year. But on a daily basis process owners are responsible to ensure that departmental activities and production procedures are planned and trained for, and executed in line with operational goals. New hazards can occur at any moment, and line supervisors must positively support employees who identify and report production hazards in the PRMS model.
- Individual sources: Hazards include individualized actions that production mechanics may take to complete inadequately defined IPs. Such action is referred to as a non-standardized workstream. IPs describe steps that are at a level suited for the mechanic to interpret. However, there may be an inadvertent lack of IP clarity that causes a margin of human error. In such cases the mechanic may, with best intentions, craft installation steps that are not consistent with another mechanic performing the same task. “O” questions are designed to bring such issues forward. However, should hazards be recognized with IPs that are not yet selected for a process walk, the mechanic should report the issue without fear of reprisal. Such an IP risk is an example of a threat to the production system. Examples include personal error, slippery conditions on the shop floor, tools that are out of calibration, inadequate protective clothing, and production rate pressures, etc. Stolzer suggests that employees think in terms of Threat and Error Management (TEM) with SMS, and PRMS adapts the same TEM philosophy. TEM requires that threats and personal errors are recognized by each employee as they occur, and that each employee manage the threat as a threat manager. While it is the employee’s responsibility to report these threats for resolution, it is management’s responsibility to remove these threats, as appropriate, from the production system. It is important to reiterate that PRMS is about mitigating risk as appropriate and within reason. Some level of risk

is inherent with every complex enterprise. No production system can be one-hundred percent risk-free as is recognized by TEM.

*Healthy PR Reporting*

For PR reporting to be successful, the enterprise must ensure the continuance of a healthy production culture as defined by PCM. This promotes and encourages employees to provide valuable PR information, which could be compromised or lost if management takes punitive action, no action and or no feedback. PR reporting is central to the proactive identification of hazards in terms of risk, and the prioritization of resources for implementation and mitigation is essential.

- Non-punitive: PRMS management must review PR reports in a positive manner, and without the employee feeling threatened or in fear of punitive action. Just as all people inadvertently err, mechanics can make mistakes that result in operational errors. Reports must be reviewed in the context of an opportunity to make adjustments to the production environment and procedures. A positive approach and meaningful solution, rather than punitive action, shows that a healthy production culture is in place.
- Action: If management is not responsive to actual or perceived PR issues, production personnel will not feel encouraged to report PRs. After submitting a report employees should receive timely feedback and see an actionable remedy, and or be informed that the PR report is taken seriously and under consideration.
- Acknowledgement: If management does not acknowledge the report, the employee will feel ignored. Employees who report PRs must be recognized in order to maintain trust in the management, which in turn strengthens PCM.

*Reactive PRM*

Investigations take place subsequent to discovery of some level of failure or PR. In the airline environment this is after an accident or incident, and conversely in the production domain it is after a production NCR, PR escapement, or flight test issue, for example. A production investigation is a symptom of aircraft production. The purpose of the investigation is to determine what happened, how, and to prevent a recurrence. Investigations are recognized as most effective when all parties work in concert with all levels of management and employees. Reactive data should be collected for the PRMS IPT ahead of the process walk to focus on the IP that may link to the issue. As transcribed to PRMS the following is compiled as guidance for a PRMS investigation:

- Fact finding and data collection
  - IP review
  - Employee interviews
  - Production data analysis
  - Quarantine and analyze damaged, failed or miss-installed hardware
  - SME interviews
  - Production line video
  - Airline participation (in case of external escapement)
- Data analysis
  - Assemble IPT to evaluate facts
  - Attain consensus on the facts, sequence of events and production system deficiencies
  - Ensure data ambiguities are resolved and understood
- Written summary
  - Summarize factual information and analytical methods/results
  - Explain gaps in data to enhance credibility of reports
- Findings, conclusions and recommendations
  - Summarize sequence of events and results of root cause analysis
  - Identify and assign specific corrective actions within production operations to prevent reoccurrence
  - Coordinate with airline in case of external escapement
- Senior management review
  - Provide senior management with review of facts and corrective action plan

- Assign and track implementation of corrective actions
- Conduct periodic follow-up assessments to ensure the effectiveness and sustainability of the corrective actions

A reactive investigation in an environment of open communication can provide information on topics that include procedural and training deficiencies. By *reacting* to the PR, the investigation can also correlate areas previously not identified and initiate *proactive* actions.

*Production Operations Data Analysis*

Production data analysis is one of the most powerful tools to monitor the health of daily manufacturing operations. Production data is both reactive and proactive. It is reactive in the sense that it captures historic deviations from standard production operating procedures. And it is proactive in that trend information may show a shift in production parameters such as increased hazards in the assembly line wing-to-body join, for example, leading to increased production time-flow. Manufacturing data that is available includes:

- Notification of (internal and or external) Escapement (NOE)
- Quality Assurance Reports (QAR)
- Production Non-Conformance Reports (NCR)
- Manufacturing Parts Requests (MPR)
- Production shipside data
- Flight test delivery reports
- Manufacturer/airline conferences
- Service Bulletins
- Design requirements

*Existing versus Predicted Hazards*

Existing hazards are those that currently exist in an organization, whereas predicted hazards are those that may manifest as a result of a change such as with an IP revision, operational change, and new supplier or partner, or changes that partners and suppliers make within their organizations. Existing hazards that have been identified should be mitigated by starting with an IP process walk. Supporting data should come from areas such as voluntary employee reporting, audits, and production data from NCRs and investigations.

Predicted hazards are a result of deliberate process or procedural change. Examples include new production tooling, production rate increases, production of a new aircraft model, a new computing system, and a change of, or new, suppliers. The IPT should identify PR issues that may surface from such changes, and then proactively treat them as predicted PR risk hazards and consider a process walk for potentially impacted IPs.

### 5.2.2 Element 7 – Production Risk assessment and mitigation

Individual production hazards are analyzed, and their consequences are assessed and communicated throughout the organization. Mitigation actions must be developed for those hazards presenting unacceptable operational risk.

*Likelihood, Severity and Assessment*

PR assessment is the analysis of the consequences of the hazards that could threaten the production organization. Field Tests adapted ICAO's "SR = L X S" formula as applied to airlines, and translated it to develop a process to identify the probability of a single point of production failure, i.e. IP risk (L).

To assess "L" in context of the enterprise production system:

1. PRMS translates ICAO's *SMS* Risk Assessment Matrix [Figure 5-2] into the *PRMS* Risk Assessment matrix [Figure 5-3].
2. PRMS refers to probability values 1 through 5 [Figure 5-4].
3. PRMS refers to severity values A through E [Figure 5-5].
4. Alpha-numeric values A through 5 are aligned with the ICAO Risk Tolerability Matrix to determine production risk tolerability levels [Figure 5-6].

5. Tolerability values are entered into the corresponding FMEA IP tasks as exercised in Field test 3 [Figure 4-19].

SMS uses the Risk Assessment matrix to quantify in-service airline risk severity (S) that can manifest from “L”. The example used in this paper’s Method/Overview was low hydraulic fluid pressure due to an airlines’ A&P error (single point of failure, L) causing a airline risk in terms of the landing gear not retracting after takeoff, an air turnback and passenger travel delays (systemic risks, S).

Conversely, the PRMS Risk Assessment Matrix quantifies “S” as to how far the IP error severity may escape (or travel) before manifesting. PR increases as the escapement moves further downstream within the production system. Although PRMS is about production system exposure to PR, the PRMS Risk Assessment Matrix as a secondary function can connect to an airline SMS and correlate the possibility of an external escapement.

PR is an integral and unavoidable aspect of aircraft manufacturing. PRMS defines the acceptable and measurable level of PR margin, but does not eliminate PR. The IP Risk Assessment Matrix provides a measure of where the IP Risk can or does manifest in the production system.

PR is managed by determining if the risk is tolerable or intolerable. SMS uses ICAO’s tolerability matrix, and PRMS is also able to use the matrix “as is” to quantify the tolerability level in the context of PR. The appropriate tolerability values are entered into the OD FMEA. Within the intent of SMS architecture, but as applied to the production world, this provides each IP step with a classification of Acceptable (A), Tolerable (T) or Intolerable (I) production risk.

| Risk Probability | | Risk Severity | | | | |
|---|---|---|---|---|---|---|
| | | Catastophic A | Hazardous B | Major C | Minor D | Negligable E |
| **Frequent** | **5** | 5A | 5B | 5C | 5D | 5E |
| **Occasional** | **4** | 4A | 4B | 4C | 4D | 4E |
| **Remote** | **3** | 3A | 3B | 3C | 3D | 3E |
| **Improbable** | **2** | 2A | 2B | 2C | 2D | 2E |
| **Extremely Impossible** | **1** | 1A | 1B | 1C | 1D | 1E |

**Figure 5-2. ICAO Risk Assessment Matrix**

| **IP Risk Probability (L)** | | **IP Risk Severity (S)** *(Place of IP error discovery / manifestation)* | | | | |
|---|---|---|---|---|---|---|
| | | *External Escapement* | *Internal Escapament* | | | *No Escapement* |
| | | **Airline / In-Service** | **Testflight / Delivery** | **Preflight** | **Downstream Production Line** | **Immediate Production Line** |
| | | **A** | **B** | **C** | **D** | **E** |
| Frequent | **5** | 5A | 5B | 5C | 5D | 5E |
| Occasional | **4** | 4A | 4B | 4C | 4D | 4E |
| Remote | **3** | 3A | 3B | 3C | 3D | 3E |
| Improbable | **2** | 2A | 2B | 2C | 2D | 2E |
| Extremely Impossible | **1** | 1A | 1B | 1C | 1D | 1E |

**Figure 5-3. PRMS Risk Assessment Matrix**

| **Probability (L)** | **Meaning** | **Value** |
|---|---|---|
| Frequent | Likely to occur many times (has occurred frequently) | 5 |
| Occasional | Likely to occur sometimes (has occurred infrequently) | 4 |
| Remote | Unlikely to occur (has occurred rarely) | 3 |
| Improbable | Very unlikely to occur (not known to have occurred) | 2 |
| Extremely Improbable | Almost inconceivable that the event will occur | 1 |

**Figure 5-4. ICAO Definitions of Probability (applied unaltered to PRMS)**

<table>
<tr><th>Severity (S)</th><th>Meaning</th><th>Value</th></tr>
<tr><td rowspan="4">Critical:<br>Airline / In-Service</td><td>Customer (airline) operational and or economic impact</td><td rowspan="4">A</td></tr>
<tr><td>External production escapement: Post delivery in-service problems requiring mitigation of escaped production issues</td></tr>
<tr><td>IP error manifests after C of A and delivery of aircraft to airline. In-service discovery of production error</td></tr>
<tr><td>Issuance of regulatory Airworthiness Directives</td></tr>
<tr><td rowspan="6">Hazardous:<br>Flight-test / Delivery</td><td>A large reduction in flight-test / delivery capability, physical distress or a workload such that employees cannot be relied upon to perform their tasks accurately or completely</td><td rowspan="6">B</td></tr>
<tr><td>Production system escapements requiring large amounts of rework and schedule impact and or late delivery of airplane to customer</td></tr>
<tr><td>Production system scheduling issues requiring large amounts of "travelled" or out-of-sequence work and or late delivery of airplane to customer</td></tr>
<tr><td>Serious incident causing negative impact to flight-test / delivery operations</td></tr>
<tr><td>Personnel injuries causing negative impact to flight-test / delivery operations</td></tr>
<tr><td>Internal escapement. IP error manifests during pre-customer testflight causing airplane delivery delay. Customer economic impact.</td></tr>
<tr><td rowspan="6">Major:<br>Preflight</td><td>A significant reduction in preflight operations capability, a reduction in the ability of employees to cope with adverse operational conditions as a result of increased workload, or as a result of conditions imparing their efficeincy</td><td rowspan="6">C</td></tr>
<tr><td>Production-line escapements requiring significant rework</td></tr>
<tr><td>Production scheduling issues requiring significant "travelled" or out-of-sequence work</td></tr>
<tr><td>Serious incident causing negative impact to preflight operations</td></tr>
<tr><td>Personnel injuries causing negative impact to preflight operations</td></tr>
<tr><td>Internal escapement. IP error manifests during pre-flight preparation. Production rework required and possible delivery delay.</td></tr>
<tr><td rowspan="5">Minor:<br>Downstream Production Line</td><td>Nuisance requiring minor rework</td><td rowspan="5">D</td></tr>
<tr><td>Production operating limitations</td></tr>
<tr><td>Use of emergengy procedures</td></tr>
<tr><td>Minor incident</td></tr>
<tr><td>Internal escapement. IP error manifests downstream in production line causing re-work and or travelled work, but production delay not incurred.</td></tr>
<tr><td rowspan="2">Negligable:<br>Immediate Production Line</td><td>Almost inconceivable that the event will occur</td><td rowspan="2">E</td></tr>
<tr><td>No escapement. IP error is realized immediately and resolved.</td></tr>
</table>

**Figure 5-5. PRMS Definitions of Severity**

| ICAO Risk Tolerability Matrix | | |
|---|---|---|
| **Intolerable Region** | 5A, 5B, 5C 4A, 4B, 3A | Unacceptable under the existing circumstances |
| **Tolerable Region** | 5D, 5E, 4C, 4D, 4E, 3B, 3C, 3D, 2A, 2B, 2C | Acceptable based on risk mitigation. It may require management decision |
| **Acceptable Region** | 3E, 2D, 2E, 1A, 1B, 1C, 1D, 1E | Acceptable |

**Figure 5-6. ICAO Risk Tolerability Matrix (applied unaltered to PRMS)**

It is important to observe the differences between the PRMS and ICAO definitions of severity [Figure 5-7]. ICAO/SMS definitions are entirely geared towards airline operational safety. Trying to embed these into the production operations is a misfit, so for PRMS the definitions were revised to align with the production domain while the scale remained constant. By comparing SMS versus PRMS severity definitions, this research argues that applying SMS as-is into the production domain is not viable.

| Severity (S) | Meaning | Value |
|---|---|---|
| Catastrophic | Equipment destroyed<br>Multiple deaths | A |
| Hazardous | A large reduction in safety margins, physical distress or a workload such that employees cannot be relied upon to perform their production tasks accurately or completely<br>Serious injury<br>Major equipment damage | B |
| Major | A significant reduction in safety margins, a reduction in the ability of employees to cope with adverse production operational conditions as a result of increased workload, or as a result of conditions imparing their efficeincy<br>Serious incident<br>Injury to persons | C |
| Minor | Nuisance<br>Operating limitations<br>Use of emergengy procedures<br>Minor incident | D |
| Negligable | Almost inconceivable that the event will occur | E |

**Figure 5-7. ICAO SMS Definitions of Severity**

*PR Mitigation*

PR mitigation is the management of potential effects of production operational hazards and resulting economic impacts. Risk management decision-making can affect multiple departments, therefore PRMS must ensure the IPT involved and familiar with the IP process walk remains active with PR mitigation.

Risk tolerability margins are defined by acceptable, tolerable and intolerable. The IPT reviews intolerable steps to understand the nature of the issues. IP XYZ Step 8 received an Intolerable rating (5C) because it could potentially (or has) cause interrupted work and disruptions with preflight operations. With a potential schedule and economic impact to the manufacturer this indicates a case for mitigative action to be taken.

Tolerable margins range from 2C to 5D. “Tolerable” is not necessarily interpreted as “OK”. For example, step 6 received a rating of 3C implying the occasional manifestation of escapement at preflight. This should also be reviewed from the perspective of schedule and economic impact perspective – it may be occasional, but how much does the escapement cost and exactly how often could it, of has it, happened? Is it really tolerable, or can a process be altered upstream to mitigate this potential or actual 3C event?

*PR Categories*

PRMS adapts the four risk mitigation categories as used by ICAO and SMS. These are used alone or in combination.

- Accept or assume risk: The PRMS manager or executive team accepts the PR with or without mitigation. By accepting the risk it is determined that that the possible negative impact, and the probability of it occurring as documented by the tolerability matrix, does not require mitigation.
- Avoid risk: The PRMS manager or executive team eliminates, revises, or re-sequences IPs to avert the PR.
- Mitigate risk: The PRMS manager or executive team approves, funds, schedules and implements one or more IP risk mitigation strategies.
- Transfer risk: The PRMS manager or executive team transfers ownership of the IP, or IP step, to a better suited production position.

*PRM Documentation*

Just as SMS requires documentation of risk assessment and mitigation activities, so does PRMS. Aircraft manufacturing is a large enterprise and already administrates multiple online computing systems. Adding PRMS to the production documentation and records system incurs costs to be evaluated and presented by the accountable executive. As with PRMS in general, the debate of implementation and maintenance costs versus value, is invoked when considering IT infrastructure requirements. Notwithstanding the cost discussion, PRMS documentation:

- Establishes managerial accountability and supports informed decision-making.
- Provides records of risk assessment and mitigation decisions.
- Gains signatory buy-in from process stakeholders who have authority to commit budget to mitigation strategies.
- Provides accountability of accepted predicted residual risks, and agreement with processes and risk determinations/decisions.
- Provides accountability to regulators who oversee the production certificate.
- Provides closed-loop data.

## 5.3 Component 3: Production Risk Assurance

*Introduction*

PRA assures there is an acceptable and managed level of production risk through the use of PRA tools and methods. It is the monitoring and feedback system to provide confidence in the entire production management team to afford assurance as to the performance of production operational systems and processes using prescribed assessment tools. PRA works in conjunction with the existing QMS, and adapts the ICAO "SMS" framework to focus on production hazard identification, risk assessment and mitigation. Production risk assurance requires an input of production performance to complete the production management cycle and make necessary changes to the affected system.

*Concepts and Definitions*

Safety assurance as described in ICAO's Safety Management Manual was derived from ISO 9001:2000. A number of states define *safety* assurance in the framework of quality assurance (Stolzer, et al., 2011). Similarly, this paper defines *production* assurance in the same context: PRA ensures procedures are carried out consistently, functional departments are in compliance with State regulations, operational problems (production hazards) are identified and resolved, continual improvement of processes and procedures and the verification that corrective actions to recognized production hazards are proven to be effective and sustainable.

As with SMS safety assurance, PRA can be carried out within the existing QMS. The PRM and PRA components require frequent interface to ensure production hazards are collaboratively managed and monitored [Figure 5-8]. It is in the areas of PRM and PRA that the enterprise requires the most attention to align with PRMS, whereas the policy and culture components require less rearrangement since they are more domain-generic in their makeup.

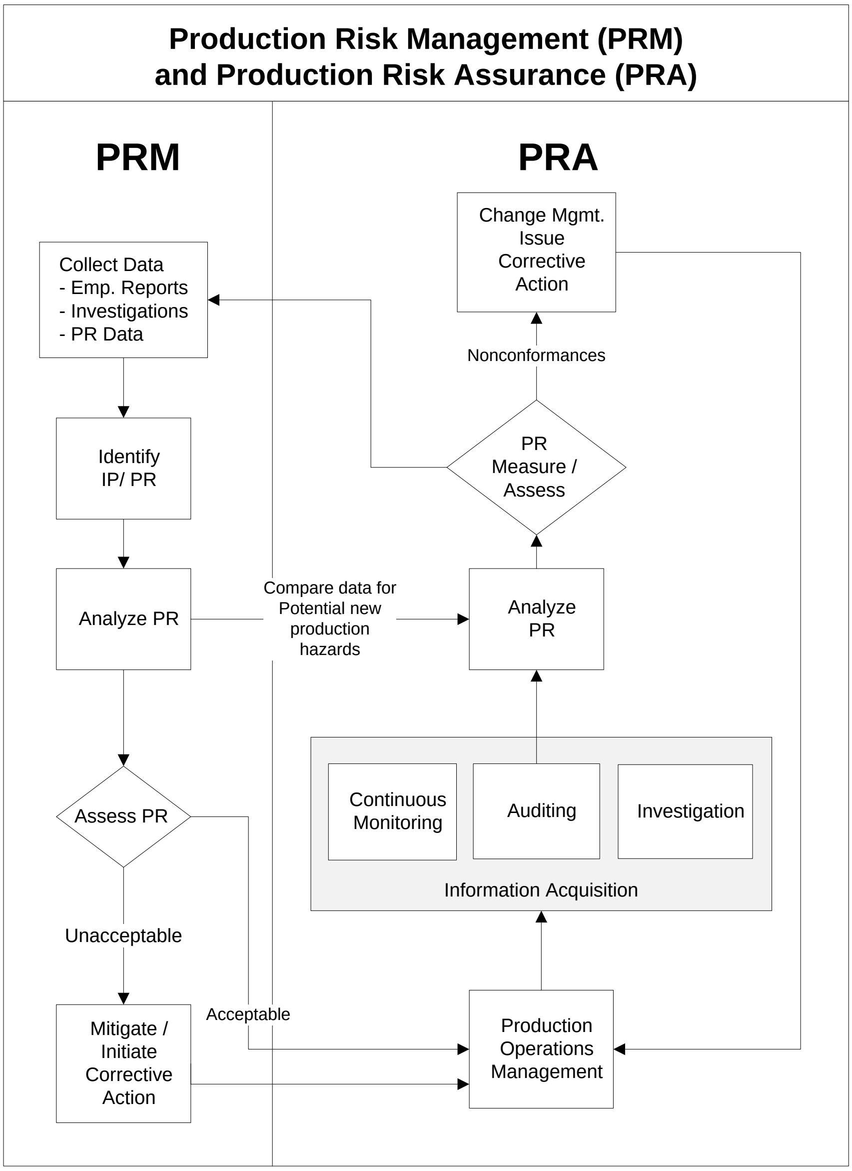



**Figure 5-8. PRM-PRA Functional Relationship**

*Parallel and Sequential PA*

PRA works sequentially when new production processes are implemented, and after existing processes are revised. In conjunction with PRA's sequential activities, *PRM* proactively identifies potential hazards associated with the change, documents the mitigation strategy and controls to manage the associated risk, and gains management approval for the associated risk. Then PRA ensures that the PR controls achieve intended objectives, and PRA provides feedback to line managers regarding the effectiveness of controls and overall health of the production system. PRA works in parallel with PRM for audits to ensure production functions are current, and to ensure the overall health of production processes and procedures.

### 5.3.1 Element 8 – Production performance monitoring and measurement

Production assurance activities focus on assessing the health of the production organization. Specific goals for improvements in all areas should be set for all senior operational managers. Production assurance should include monitoring of external sources of production information and include participation in production groups or production data sharing organizations.

Production assurance is conducted by measuring the outcomes of operational activities that result in the production of aircraft by the organization. In SMS, and conversely with PRMS, production assurance elements are applied to gain an understanding of the human and organizational issues that can impact production risk. As transcribed to PRMS, performance monitoring and measurement may be accomplished by assessing organizational processes through the lens of the following perspectives (ICAO, 2009):

- Responsibility: The manager who is accountable for PRMS operations.
- Authority: Who can direct, control, or change PRMS procedures, and make key decisions on PR acceptance issues.
- Procedures: Specified ways to carry out PRMS operations that correlate the “what” objectives into “how” activities.
- Controls: Facets of the system such as hardware, software, and procedures that support PRMS.
- Interfaces: Lines of authority between departments, communication throughout PRMS, and consistency of PRMS between work and employee groups.

- Process measures: Means of providing feedback to responsible managers to ensure that PRMS outputs are as planned.

*Production Data Sources*

Aircraft systems, structures and power plants are organized by ATAs (APPENDIX A). ATAs are common standards, or “chapters” for all commercial aircraft documentation. This unique aspect of chapter numbers is used for airplane models regardless of the manufacturer. Thus an ATA chapter reference number for a Boeing 747 is the same as for an Airbus A380, Embraer ERJ 145, Gulfstream V, and BAe 125. For example, Fuels is ATA (Chapter 28), Oxygen (Chapter 35), Electrical Power (Chapter 24), Doors (Chapter 52), and so forth.

This research used the count of NCRs from ATA 28 as the leading indicator to focus on IP XYZ. Aircraft manufacturers and their IPTs typically organize around ATAs, so these teams are already in place and can readily be aligned to support a PRMS model. Production data is ATA-specific and includes:

- Notification of (internal and or external) Escapement (NOE)
- Quality Assurance Reports (QAR)
- Production Non-Conformance Reports (NCR)
- Manufacturing Parts Requests (MPR)
- Production shipside data
- Flight test delivery reports
- Airline performance quality reports
- Airline equipment quality reports
- Continuous Operations Safety Program (COSP)
- Maintenance communications from airlines to manufacturer
- In-service airline reliability and maintenance data (i.e. MTBF)
- Manufacturer/airline conferences
- Aviation Safety Information Analysis and Sharing (ASIAS)
- Regulatory Safety Bulletins

- Service Bulletins
- Design requirements

Such data is used by aircraft production enterprises for metrics. Depending on the level of PRMS investment, the data may be assimilated into one PRMS database and with the use of an algorithm, prospective problem IPs may be proactively identified. Such leading indicator data is provided ahead of process walks, and supports traditional reactive PRM activities.

*Measuring PR Performance*

PRMS uses PR indicators to measure the pulse of the production system, and establishes PR targets. Indicators align with production data sources, as defined by the manufacturer based upon specific enterprise expectations. PR targets connect to PR values to maintain economic margins. Examples that the manufacturer may select include:

PR Indicator

- NCRs
- Not meeting production rate
- Internal production escapement
- External production escapements
- Economic / over budget
- Workforce disruption such as labour strike
- Supplier disruption
- Regulatory violations
- Workforce accidents or incidents
- Missed employee training and certification

PR Target

- Optimize/tighten threshold values in IP Tolerability Matrix
- Clarify IPs
- Reduce number of production NCRs to a maximum acceptable threshold

- Reduce number of escapements to a lower acceptable threshold
- Reduce rework on production line, and rework that occurs downstream (travelled work) as a result of line production errors
- Reduce out-of-sequence work
- Increase production rate
- No missed workforce recertification
- Zero workforce accidents or incidents
- Improve management response time to employee reports
- Reduce supplier flow time

PR Value

- Clarify IPs: Lost time due to interpreting unclear IP steps
- Reduce rework: Lost time on unaccepted work, and on time taken to make corrections and or rework the installation
- Increase production rate: Deliver more aircraft per year and increase revenue

### 5.3.2 Element 9 – Management of change

External or internal changes may introduce new hazards to production operations activities. Processes must exist to manage organizational responses to regulatory changes, major changes in operational procedures or new activities. Production reporting systems should have processes established to identify new risks and actively monitor performance in new areas of the operation.

ICAO states … a formal management of change process should identify changes within the organization which may affect established processes, procedures, products, and services. Prior to implementing changes a formal management of change process should describe the arrangements to ensure safety performance (ICAO, 2009, 9.8.4).

As applied to PRMS, "safety performance" becomes "PR performance". PRMS transcribes change management as the documented strategy to proactively identify and manage PR that can accompany a significant change with the aircraft manufacturer, whether operational, technical, or organizational. Examples for the PR change management process include:

- production operations expansion or contraction
- changes to existing production systems, equipment or programs
- new aircraft models and procedures
- outsourcing of production operations
- changing suppliers and partners
- organizational changes to include a merger of reorganization

Changes take place in manufacturing enterprises in order to generate new aircraft models, create derivatives of existing models, deploy up to date manufacturing technology, avert escapements, and so forth. Changes keep the enterprise competitive in the short and long terms. While the outcomes of changes are included with the manufacturers' regulatory oversight, the actual *process* of change is less established (Quinn, 1996). PRMS, as with SMS, suggests the need to better formalize and document the change process and better substantiate change decisions. This also provides a permanent record of why decisions were made that can be accessed and understood by employees who were not at the enterprise when changes were made.

Two forms of change are identified – incremental change and deep change. Change management has been greatly studied with quality and human factors researchers for decades. As applied to PRMS, incremental change management is applicable to areas such as employee reports, audit reports, NCRs, performance metrics, etc. Deep change represents a commitment by the organization to escape a slow death to extinction or insignificance (Quinn, 1996). An example would be an aircraft manufacturer's recognition that its existing airplane model is becoming outdated. In response, significant investment is made to design and manufacture a new model in order for the company to remain competitive. Change management is a component of PRMS, and PRMS adopts industry standards and conventions for this activity.

*Change Management*

The FAA ATO developed a change management approach to ensure hazards are identified and unacceptable risk is mitigated prior to making procedural, process, or system change. As applied to PRMS it is initiated by a change proponent or sponsor who performs PR analysis. Terms are transcribed to PRMS as follows:

- PR Management Panel: A PRMP is a group of carefully selected stakeholders from various organizations affected by the change. The PRMP identifies potential production hazards, conducts PR assessment, develops suggested mitigation strategies and completes PRMD.
- PR Management Document: The PRMD is an effective tool to summarize (record) the PR analysis, capture the prioritized hazards and associated PR mitigations and serves to enable the management team to understand the change, associated PRs, mitigation strategies and commitment to fund and implement the mitigation strategies.
- PR Management Decision Memo (PRMDM): Should the change proponent conclude that no PR will be introduced into the system by the change, a PRMDM is prepared to document the justification and rationale.

The PRMP assembles the ATA IPT to provide senior management with a technical assessment of the proposed changes to existing systems or processes. The PRMP is scalable to the size of the aircraft manufacturing enterprise. The completed PRMP completes the PRMD and is reviewed and signed by leadership. Signatures represent the acceptance of the PR analysis process, the acceptance of predicted residual PR after implementation of mitigation strategies and the commitment of resources to implement the PR mitigation strategy. Further discussion of this process is described in the ICAO SMS Implementation Guide – IATA, April 2010a, 6.2 (Stolzer, et al., 2011).

Eric Lofquist argues that traditional metrics in the civil aviation industry of reporting incidents and accidents do not fully capture the true state of an evolving organization and are, at best lagging indicators (Lofquist, 2010). As transcribed to PRMS, he proposes a balanced approach to managing risk as a system that monitors risk in three temporal phases embedded in the organizational culture. These phases - proactive, interactive and reactive - are mechanisms and measures that are both separated in time, and include both leading and lagging indicators that are both qualitative and quantitative, and include production personnel’s perceptions of evolving production systems during change. He argues that this will provide a balanced approach to the production system’s risk at any given point in time and give organizational leaders leading indicators from which to make proactive measurements. This approach is compatible with SMSs already place with most civil aviation-related organizations, and supports an integrated system such as a manufacturing enterprise with multiple overlapping certificates.

### 5.3.3 Element 10 – Continuous Improvement of the PRMS

Production assurance utilizes quality tools such as internal evaluations or independent audits to assess organizational health from a safety perspective. Onsite assessments of operational management systems on a recurring basis provide opportunities for Continuous Improvement (CI) of processes and procedures for each functional area of the organization. PRMS audits are aligned with ISO 9000. ISO 9000 is a series of standards that are already part of aviation industry certification processes (Hale, et al., 1997).

*Plan-Do-Check-Act*

Aircraft production companies continuously go through organizational changes to remain viable in the market. Management systems evolve based upon lessons learned, remediation of flaws in production operations, and identification of improvement opportunities. Continuous improvement and learning is inherent to a healthy production culture that enables proactive PR management through process assessment and improvement.

At its functional working level, PRM identifies and mitigates aircraft PRs, and PRA assures effectiveness of PRM [**Error! Reference source not found.**]. However, the relationship between PRM and PRA is different at the organizational level. Here, PRA supports enterprise management of production, and delivery of aircraft and services to the customer. PRA is part of the overarching business primary and operates unlike its working level RAA.

Transport Canada, EASA, the FAA, and other regulatory bodies employ the PDCA tool to manage organizational change. PDCA (plan–do–check–act or plan–do–check–adjust) is an iterative four-step management method used in business for the control and CI of processes and products. It is also known as the Deming circle/cycle/wheel, and Shewart cycle - control circle/cycle, or plan–do–study–act (Deming, n.d.). As adapted to PRMS, PDCA encompasses the working levels of PRM and PRA *and* includes the production enterprise at large for continuous improvement [Figure 5-9]. PRMS uses this tool to ensure compatibility with Transport Canada, EASA and the FAA who utilize a version of the PDCA cycle with SMS.


**Figure 5-9. PRMS Plan-Do-Check-Act**

*PRA and CI*

PRMS relies on existing company QMS infrastructure and personnel. Similar to conventional QA, PRA includes the independent activity of providing evidence needed to establish confidence, among all concerned, that PRMS is being performed effectively. At the enterprise level, PRA supports CI by assuring production quality through independent audits and evaluation of established processes, procedures and documentation. In contrast, at the functional level, PRA QC is the responsibility of the line manager to oversee the day-to-day activities of inspectors who ensure compliance of production activities such as IP accomplishment. PRA operates with generalists in the enterprise context. And with QC personnel, PRA provides technical experts who identify procedural deviations and errors on the production line.

*Management Review*

An essential ingredient of SMS is management review that requires a periodic formal meeting of senior leadership to review the health of the production enterprise. The output of PRM and PRA activities are primary metrics that indicate opportunities for improvement. The management review process can include a number of agenda items to assess the health of the organization in terms of regulatory compliance, PR, efficiency, productivity, incident and accident reports, status of corrective and preventative actions, audit results, and so forth.

- production and quality performance audits
- operational results that reflect production process or production system deficiencies
- audit results, to include internal evaluation, internal audits and regulatory feedback
- Regulatory violations
- Incident and accident investigation results
- Status of corrective and preventative actions

- Review of prioritized list of production operational risks:
    - production
    - quality
    - security
    - environmental
- organizational effectiveness to include division of work streams
- changes in regulatory policy or legislation

To paraphrase Stolzer: Production Risk Assurance is nothing more than assuring production risk through the use of quality assurance tools and methods, all with a focus on production. The central message to all of us is to create a simple alignment of the work streams in production, quality, security and environmental disciplines so that the manufacturer can understand and embrace the processes and tools. Otherwise the leadership will continue to deal with inefficiency, confusion and redundancy (Stolzer, et al., 2011).

## 5.4 Component 4: Production Culture Management

The trend around safety culture originated after the Chernobyl disaster brought attention to the importance of safety culture and the impact of managerial and human factors on the outcome of safety performance (O'Conner, et al., 2008), and although the term of “organizational culture” became known in businesses in the late 80s and early 90s (Kinicki, 2011), *corporate culture* was already used by managers and addressed in sociology, cultural studies and organizational theory in the beginning of the 80s (Smircich, 1983).

*Introduction*

PCM requires the accountable executive to advocate PR practices that will improve the organizational production culture, provide effective production training for all employees, and communicate production information that promotes adherence to standard production operating procedures and consistent behaviours. Similar to ICAO’s description of safety promotion, PRMS defines PCM in the context of Training and Education, and Production Risk Communication.

*Concepts and Definitions*

PCM requires the PRMS accountable executive to demonstrate the mindset that is expected of employees. The entire management team must “walk the talk” to underscore the importance and value of a healthy production culture. The UK CAA categorized training into four levels relative to SMS, that also apply to PRMS:

- operational staff
- managers and supervisors
- senior leadership
- accountable manager

In order to provide more awareness of the relationship between culture and organizational identity, a conceptual path model was created (Lin, 2012). The findings showed that, in the airline model, safety culture has been strengthened as a result of the implementation of the SMS. Furthermore, the loyalty factor of the organizational identity is found to positively and significantly predict the performance of SMS through the safety culture. The same benefits should also apply to PRMS since humanistic characteristics and psychology (or soft attributes) of people between aviation domains is similar.

Organizational culture is a set of shared mental assumptions that guide interpretation and action in organizations by defining appropriate behaviour for various situations. At the same time although a company may have its "own unique culture", in larger organizations, there are diverse and sometimes conflicting cultures that co-exist due to different characteristics of the management team. The organizational culture may also have negative and positive aspects (Ravasi & Schultz, 2006).

Yi Hsin Lin researched the relationship between safety culture and the organizational identity of a safety management system, in order to provide more awareness of how airline employees perceive organizational identity and safety culture as they successfully implement SMS (Lin, 2012). By transposing the findings to PRMS, it can be argued that production culture – a subset of organizational culture - can be strengthened as the result of implementation of a PRMS. Furthermore, the loyalty factor of organizational identity should be found to positively and significantly predict the performance of PRMS through production culture management.

### 5.4.1 Element 11 – Training and education

The organization must identify personal safety training requirements for each level of management and for each employee group. Production training for operational personnel should address production responsibilities, including complying with all operating and production procedures, recognizing and reporting hazards and ultimately ensuring that employees have the knowledge and skills to safely complete production activities.

PCM requires different types of training for different enterprise levels. Production personnel must know how and when to submit hazard reports, how the reports are processed, and the results of the reports. Managers and supervisors require training for PR identification, assessment and mitigation, and the accountable executive focuses on PR leadership strategy.

While PRMS leadership must be knowledgeable of all PR aspects, production line employees (although familiar with PRMS at large) focus on detailed processes that are part of their day-to-day functions. ICAO, 2009, 9.11 provides guidance for training and education that translate to PRMS:

- documented process to identify training requirements
- validation process that measures the effectiveness of training
- indoctrination training incorporating PRMS, to include human factors
- initial (general PR) job-specific training
- recurrent PR training

PRMS staff involved in leadership, change management, continuous improvement, or investigations require training for:

- roles and responsibilities pertaining to PRMS and QMS

- event investigation and analysis techniques
- audit principles and techniques
- management system design, analysis and implementation
- root cause analysis
- human and organizational factors
- communication and training techniques

### 5.4.2 Element 12 – Production communication

Production communication includes information on production culture, reporting systems, investigation results, production risk lessons-learned and management actions taken as a result of employee PR reporting.

*Production Culture*

As with SMS, PRMS uses Dr. James Reason's definition of safety culture and applies it to production culture [Figure 5-10]. This consists of five elements:

- Informed Culture: people are knowledgeable about the human, technical, organizational and environmental factors that determine the *production risk* of the enterprise as a whole.
- Flexible Culture: people can adapt enterprise processes when facing stressful and temporary *production* operations.
- Reporting Culture: people have enough trust and confidence in *PRMS* to respond to PR reports in a way that justifies the time and effort to submit the report.
- Learning culture: people at all levels of the enterprise continue to identify opportunities for improvement and implement reforms to *production operations* procedures and processes.
- Just culture: a just culture, for the most part, refers to the attitude of the management team to deal rationally, fairly and justly with employees who make unintentional mistakes.

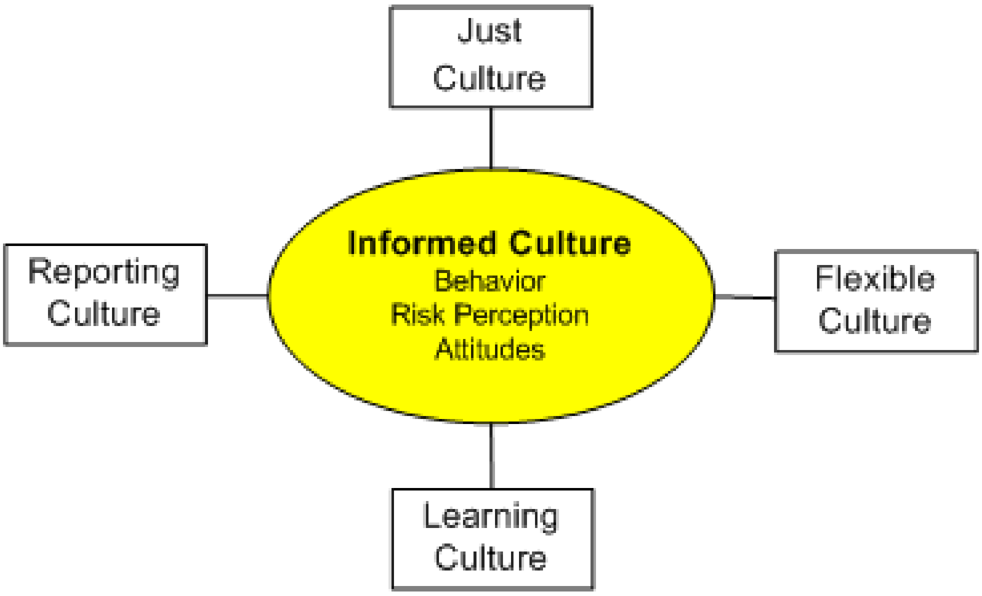



**Figure 5-10. Organizational Culture**

Communication of production information is a key responsibility for the production manager and for the organization as a whole. Continuous improvement and learning is accomplished through the sharing of lessons learned from investigations, hazard report analysis and operational safety assessments. Feedback to operational personnel such as examples of procedural improvements as a result of production reports is an essential feature of production communications. Communication includes PR culture information, reporting systems, investigation results, PR lessons learned and management responses to employee PR reporting.

Communications to specific employee groups ensure engagement is specific to job types such as to production line supervisors, technicians, QA line inspectors, installation mechanics, production planners, production controllers, crane operators, machine operators, painters, tool crib personnel, and so forth.

Organizational culture studies require cultural assessments to be measurable, and this data is provided to PRM via the PR Culture Assessment tool as customized for this study (Appendix C).

*PR Summit*

Similar to SMS safety summits, PRMS schedules an annual stand-down or PR summit where senior leaders and production operations executive management meet to align PRMS across the enterprise. The agenda may include:

- review of RAAs
- review of enterprise culture and strategies to improve culture
- review of enterprise and regulatory relationship
- assessment of PRMS processes
- PR hazard tracking system and effectiveness
- PR data analysis metrics

## 5.5 Summary of PRMS Model

PRM and PRA are the most salient differences between *safety* risk management and *production* risk management. Put simply, SMS is *in-service (airline)* risk management while PRMS is about *aircraft production risk*. This research recognized that there is not a *direct* correlation from a shop floor IP event to an airline risk. But there are a string of events (or non-events), that can take place during production that can lead to an external escapement that can subsequently be identified within airlines' SMSs. PRMS uses *risk* philosophy to proactively identify and mitigate production risk. It identifies IP risk probabilities (L), uses a risk assessment matrix to quantify the severity of how far downstream the resulting IP error may travel (S), and uses a risk tolerability matrix to determine if mitigative action is or is not required. A PR that manifests during production is an *internal* escapement. An *external* escapement is a PR that manifests after the airplane receives the C of A and is delivered to the airline at which point the airline SMS reviews the risk impact in terms of reliability, safety, inconvenience, economic, etc. Airline and manufacturers do, or course, collaborate for resolution at times of external escapement.

PRMS uses data collection methods to identify risk within the production system. Field test 3 included human factors. It gathered data such as how an aircraft mechanic may use poorly defined IPs, use tools that may not be most suitable for the job at hand, use insufficient lighting in a confined space with limited access, or work in cold weather. It targets operational risk facing the manufacturing organization, whereas SMS focuses on risks associated with airline operational safety. For PRMS to align with SMS philosophy the elements of PR identification, and PR assessment and mitigation were established. Using the context of the Australian Civil Aviation Authority (CASA) for risk, risk is be termed as “low enough that attempting to make it lower, or the cost of assessing the improvement gained in an attempted risk reduction, would actually be more costly than any cost likely to come from production risk itself”. As with SMS, PRMS identifies risks through a concert of reactive and proactive means. Reactive data is historical and in the form of “incoming data and trends” Proactive data is gathered from the process walk and assesses prospective or future events that may manifest if mitigation does not happen.

# 6.0 Discussion and Evaluation of PRMS

## 6.1 Risk Management in High-Risk Domains

### 6.1.1 Aircraft Production Risk Mgmt *is not* Airline Safety Risk Mgmt

The aviation industry includes the domains of the aircraft lifecycle as identified in this paper. Regulators attempt to apply SMS across all three domains. When investigating the nature, or primary function of each domain, it evident that the *primary type of risk* for each domain is different. For this reason this research proposes that the concept of applying one generalized SMS across the aviation industry at large is not feasible.

As industries became more complex over the last century the necessity to manage risk – or manage safety - became increasingly essential to conduct business enterprises. Depending on the industrial sector, or professional field, one term is preferred over the other but both are generalized as the same even though used for different domain-centric implications (Harms-Ringdahl, 2004) . Little systemic research has been completed on the applicability of different safety (or risk) management methods, or the limitations of generalizing safety/risk management across and within industries and domains. While the practices of human factors training and incident reporting promote risk management, successful design and implementation varies substantially due to differences across working domains. The one-size-fits-all SMS gold standard approach to designing and running one SMS across all industrial domains is considered to be difficult or possibly even dangerous to follow (Grote, 2012).

By using three attributes to benchmark and design an SMS program, a clearer understanding emerges of why one SMS does not work for both the airline and production operations domains. These attributes are (1) the kinds of safety (or risk) to be managed, (2) the general approach to managing uncertainty as a hallmark of organizations that manage safety or risk, and (3) the regulatory regime within which safety or risk is managed (Grote, 2012). The attributes align with industry-accepted SMS definitions and standards as discussed in this paper and with the recognized SMS features to include:

- Safety (risk) policy
- Safety (risk) resources and responsibilities
- Risk identification and mitigation
- Standards and procedures
- Human factors based systems design
- Safety (risk) training
- Safety (risk) performance and monitoring
- Incident reporting and investigation
- Auditing
- Continuous improvement
- Management of change

The approach to designing SMS architecture framed with these three attributes and with the above features is subject to the enterprise domain, and not necessarily to the industry in general, i.e. aviation.

### 6.1.2 Type of Risk - Process versus Safety

It is essential to differentiate between process risk and personal safety risk (Hopkins, 2009). The salient distinction between airplane production and airline operations is that production is primarily about building airplanes at a predetermined rate, with minimal production risk, to meet enterprise goals. Production is concerned with process-driven work tasks that if not executed on schedule, can jeopardize production rate. Or if not performed properly and the IP error left undetected, the airplane may be subject to delivery with defects in the context of production escapements. As described in this paper, production escapements in turn invoke varying types of downstream risk – albeit internal or external. Production personnel safety is a secondary function to production risk, such as a mechanic sustaining a shop-floor injury that may impact the scheduled completion of an IP, or the engineering department not providing support to clarify design issues to avert production confusion and negative rate impact.

Conversely, the primary function of a commercial airline operation is to transport people safely. Any airplane operational safety risk is directly connected to the personal safety risk of the customer, or the flying public, which can jeopardize the airline enterprise. However, to support airline operations, the aircraft *maintenance process* that sustains safe flight operations requires the secondary function of process-driven work tasks that align more closely with production risk architecture.

The distinction between process risk and safety risk was evidenced during the field tests of this research. Field test 1 attempted to apply airline SMS architecture to the production environment. An effort was made to include unadjusted safety risk management to a domain that is primarily concerned with production risk. Field test 3 showed that with production risk management as the primary focus of the resulting PRMS architecture, PR can be managed with similarities to SMS. But it is not the same – SMS could not just be transferred to production operations. To achieve PRMS, the Safety Risk Management component was adjusted to Production Risk Management, and the Safety Assurance component to Production Risk Assurance.

This paper recognizes the different primary risk management focuses of airlines and aircraft manufacturers. Depending on the aviation industry domain, process risks and safety risks must be identified and assessed as primary or secondary functions. There is little conceptual and empirical knowledge on how measures aimed at process safety or personal safety yield their affects and how they interact, which constitutes and very significant need for future research (Grote, 2012). This paper demonstrates that is it important to understand what the primary risk focus is, whether safety or process, before designing an SMS, or SMS-like architecture.

### 6.1.3 Approach to Managing Type of Risk

Along with recognizing the *type* of primary risk to be managed, the *approach* to managing the risk must be defined. The traditional premise is to manage and minimize risk through regulatory oversight, bureaucratic organization, rigid standards, and automation of work processes with limited degrees of freedom for employees (Taylor, 1967, c1947). More conventional theory espouses flexibility to empower organizations and employees with a degree of freedom. This provides for some actions to be self-directed rather than rigidly following fixed plans. Typically, high risk domains such as airline operations and aircraft production manage safety and process risk with the traditional methodology due to the consequences of uncontrolled uncertainties (Grote, 2012). SMS recognizes the value of approaching risk management with a balance of traditional standardization and a limited degree of self-empowerment – or a balance between stability and flexibility.

The type of primary risks for airlines and manufacturers are different, but given that both are in high-risk domains, the philosophy of managing risk is transferable, but not the exact architecture as tested by the adaptation of SMS to PRMS architecture.

### 6.1.4 Regulatory Considerations

Although some degree of self-regulation is provided for, aviation regulatory bodies are mostly traditional due to the high-risk nature of the aviation industry (Business & Commercial Aviation, 2006). This is consistent as evidenced by domestic and international aviation regulatory bodies that are in various stages of requiring SMS for aviation domains. This research considers all aviation regulatory bodies and makes the case that SMS is applicable exclusively to airlines, whereas a similar but different architecture that is specifically production-risk centric should be recognized as applicable to the aircraft manufacturing environment.

### 6.1.5 Risk Management Design

To provide some guidance on how risk management should be designed, three components of safety/risk management are considered – standards and procedures, safety training, and incident reporting and investigation. These are among components most commonly introduced in high-risk industries while also being in need of adaptation to particular circumstances and domains (Grote, 2012).

### 6.1.6 Standards and Procedures

Standards and procedures are relevant to high-risk domains. Rules and behaviour identify how actions, such as Installation Plans on the production line or Task Cards during aircraft maintenance, relate. Rules are the written for instructions, such as the IP, that when mature are repeated with a high degree of regularity. Behaviour describes the qualitative, or subjective, way in which the person routinely carries out the rules. While it is important to have stability in order to provide a consistent and repeatable process, PRMS requires some flexibility for frontline workers to raise the need for process changes in cases where the rules and behaviour – resulting in actions – may have become misaligned over time. (Becker & Zirpoli, 2008). This balance between stability and flexibility is part of the production culture component.

### 6.1.7 Safety and Process Training

Personal safety training is typically associated with individual and team safety. It is common in high-risk domains (Burke, et al., 2006). In recent years many high-risk domains have invested in personal training since accident analyses show malfunctioning coordination as precursors to accidents (Salas, et al., 2007). In the airline business a personal safety risk may transfer to a flight operations (primary) risk, whereas in the aircraft manufacturing business a personal safety risk may translate to a (primary) production risk, such as a mechanic falling from a platform and causing a production stoppage. For both the airline and manufacturing aviation domains personal safety training is a transferable piece of SMS to PRMS architecture.

PR training for PRMS is about informing personnel of how their process actions can affect the production system in the context of situational awareness or errors and immediate or downstream consequences. While PR training focuses on the production system risk, safety training focuses on personal safety which may as a secondary function impact production.

### 6.1.8 Incident Reporting and Investigation

Incident and accident reporting aligns with the Production Culture Management component of PRMS. Such reporting can only work when blame and punitive action is avoided (Dekker, 2008). An example would be a mechanic who notes that another worker routinely completes IPs in order to meet the time allocated for task completion, which keeps the production supervisor satisfied that production rate is staying on schedule. However, for the task to be completed on-time, the mechanic moves to a subsequent IP step without providing process time for the first step to complete which requires curing of a sealant. The mechanic is not concerned with this, as he notes, he considers the sealant to be cured before he moves to the next step, and it is the IP step/time allocation that is incorrect. The second mechanic, in the spirit of a blameless culture, should feel comfortable to advise the supervisor of the issue so the IP can be revised, or the mechanic who considers the sealant to be cured – to be better trained to understand the necessity of a full cure time.

## 6.2 PRMS and the Manufacturing Domain

ICAO annexes mandate the provision of an SMS framework to govern aviation worldwide. It is applicable to service providers such as maintenance organizations, as well as enterprises responsible for type design and/or production of aircraft, i.e. aircraft manufacturers. Simultaneously, the FAA is working on how to apply SMS, and AC120-92A provides guiding principles for the entire aviation/aerospace industry. During November 2010, the FAA issued a notice of proposed rulemaking (NPRM). Although the proposal only covered Part 121, the agency stated that the NPRM would provide the groundwork for other facets of the industry. “The FAA developed these general requirements with the intent that in the future they could be applied to other FAA-regulated entities, such as Part 135 operators, Part 145 repair stations and Part 21 aircraft design and manufacturing organizations and approval holders …… the agency also says it does not intend for the NPRM to cover contractors, subcontractors or organizations not directly regulated by FAA” (Lynch, 2011).

In other words, the goal is to mandate SMS for all domains of the airplane lifecycle. This includes the Identification of safety hazards; Remedial action to maintain safety performance; Continuous monitoring; Improvement of SMS performance; and interfaces between departments within an organization as well as between organizations and external contractors

Aviation organizations around the world are aware of the importance of implementing SMS – but regulatory direction and mandates have been years in the making. “There is already a Notice of Proposed Rulemaking (NPRM) from the FAA for the implementation of SMS for air carriers and airports, and this same methodology and requirements will apply to the rest of the aerospace industry, so there needs to be a concerted effort from industry to start understanding and implementing this new way of managing safety more effectively, otherwise industry will meet a brick wall when trying to submit a proposal or meet project requirements at least initially for civilian projects” (Fuentes, 2011).

Field tests during this research indicate that taking a stock SMS and applying it to the manufacturing domain is misguided. The goal of SMS is to address the organizational factors that have an impact on the safety of the vehicle, system or final product. It is about a culture of product reliability so that the overarching airplane lifecycle system and aircraft are safe. SMS addresses air operational safety as the primary function, but the manufacturer’s primary function is to produce aircraft with minimal production risk. Further upstream in the lifecycle, airplane design engineers use extensive calculations to substantiate the safety and reliability of the airplane system and airplane subsystems. Designing a safe airplane is a primary function of aircraft engineering, flight operational safety is a primary function of airlines, and the primary function of production is to build the airplane as certified by the Type Certificate. Production achieves this by building aircraft via production risk management – not safety risk management. Personnel safety is a *supporting* (not primary) component of production, thus a PRMS should be architected accordingly. Manufacturers operating under the FAR Part 21 certificate incorporate Quality Management Systems that encompass IS9000 and AS9100 standards. These align directly with PRMS architecture components to allow the manufacturing organization to constantly increase the level of production performance.

A further challenge is in implementing the interfaces between departments within an organization, as well as between organizations and external contractors. Boeing’s organization is a national and multinational effort. The production supply chain has many primary suppliers, and sub-suppliers. Global partners design and build large sections of the airplanes that are shipped to locations in the USA for final aircraft assembly. The FAA is challenged with the concept of putting an overarching manufacturer “SMS”, and manufacturer to airline SMS interface, in place for USA based enterprises. The FAA’s NPRM “does not intend to cover contractors, subcontractors or organizations not directly regulated by FAA”. This further complicates implementation for the globally connected manufacturing enterprise. The administrative and practical implication of being “SMS” compliant only within the FAAs jurisdiction while overseas suppliers and contactors do not have to meet FAA oversight, further compounds the practicality of implementation – even if “SMS” did fit in the manufacturing domain.

But, if at some point the FAA includes manufacturers’ overseas contractors and suppliers, given the complexity of Boeing’s 787 supply chain and production system for example, to meet FAA SMS objectives the FAA would have to certify an immense global infrastructure for the 787 production program alone, and link/flow the data into international SMS-compliant airlines that fly 787s. Again, applying one gold standard SMS across all industry domains even in a less convoluted business model is misguided. However, applying a domain specific SMS, i.e. a PRMS model for the production domain, should be feasible for the manufacturing domain of the airplane lifecycle.

## 6.3 PRMS and the Maintenance Domain

### 6.3.1 Reducing Risk in MROs

SMS is taking foot with airlines. It is now moving into MRO's shop floors. To be successful in this domain a thorough understanding of its application to aircraft maintenance must be understood. In Aviation MRO, Komarniski (President, Grey Owl Aviation Consultants; Manitoba) states that *SMS focuses on the safety of the aircraft* itself. Yet, management often is quick to view it as an employee occupational health and safety measure. "Their reaction to SMS is, 'we've had an employee safety program in place for years,'" he said during a recent SMS workshop. "But if a *maintenance procedure* is not done right, it could injure the person doing it, as well as damage the airplane." Komarniski's comments align with the importance of differentiating between process and personal safety risk that was addressed in section 5.1.2 of this paper.

Komarniski comments on MRO maintenance procedures as process-driven tasks. By using the same argument for not using SMS for manufacturers, this paper argues that applying a stock SMS into MROs is misguided, but a PRMS approach does align with the MRO domain. The primary function of an MRO is to maintain aircraft per task cards and deliver aircraft back to revenue service, just as manufacturers build airplanes per task cards (or IPs) and deliver the aircraft to revenue service. The manufacturers' and MROs' primary function is to mitigate production risk (not safety risk). Airlines' *primary* function is flight safety. Employee occupational health and safety is a *supporting* function common to airlines' safety risk, manufacturers' production risk, and MROs' production risk. As Komarniski notes, employee safety is often confused with airline operations flight safety risk. Conversely, employee occupational health and safety should not be confused with MROs' and manufacturers' production operations risk (Overhaul & Maintenance (OVMT), 2009).

SMS and PRMS architectures each require tailoring of the four components, but there are also commonalities. For both architectures, personnel safety and training (as supporting functions) are included with organizational culture, but the type of safety and training is specific to the domain. “PRMS” shop level employees must fully support the process. Without their backing, technicians may perceive “PRMS” as just another flavour of the month that will be pursued for awhile and then discarded”. “Employee training must be established so they will understand what “PRMS” will do for them”. Komarniski also emphasizes the importance of a friendly” reporting system, so that once a report is submitted, top management can respond quickly with the corrective action to be taken. For MROs and manufacturers the response may be the need for training, the use of proper tooling, a new or revised repair or manufacturing process, or changes to the way work cards and installation plans are written. Situational Awareness for MROs and manufacturers is a concept that should be considered for training. To mitigate production risk, mechanics should be aware of how their tasks impact downstream production or repair events. If they miss-perform a task they should be aware of the impact on production rate, in that it may generate downstream rework for example, and how it may delay the return of an airplane from MRO to revenue service. Aspects of training and a non-threatening reporting system are included in the production culture management component of PRMS. As with PRMS in the manufacturing domain, the culture and climate must be clearly documented and understood in the MRO domain (McDonald, et al., 2000).

As of 2009 SMS was moving to regulatory implementation with MROs. ICAO Annex Six, mandated that its 190 member states establish SMS requirements for their MRO shops by Nov. 19, 2009. Transport Canada has required repair stations working on commercial airliners to file an SMS plan with the agency since 2005. But as with SMS implementation at Part 121 airlines there is confusion to exactly what it is, how to implement, and how long the “requirements” will look more like industry standards or recommendations rather that fully implemented and audited requirements (Goglia, 2010). “Don’t make this too complicated” said Bob Huberston of the MITRE Corporation. Complications stem from various sets of rules that must be followed. At present, ICAO SMS guidance is available, and a final FAA rule is the works. But focussing on compliance with a blind eye to other hazards may not help organizations achieve their safety goals (Moody, 2008).

SMS struggles with airline implementation, not because the safety management concept is seen as out of place with airlines, but because in part, of legalistic and administrative issues such as reporting requirements, and oversight capacity of regulators. Implementation of “SMS” with manufacturers and MROs will be even more convoluted. Findings from this research indicate that stock SMS architecture does not fit in a process-driven MRO domain whose primary function is mitigated through production risk – not safety risk – management.

### 6.3.2 Integration of the MRO Domain

Air carriers’ are responsible for the work carried out by maintenance providers who they contract with. The operator’s quality organization is focused on assuring the MRO is in compliance with Part 145 requirements. However, the air carrier does not need to understand the detailed nuances of running an MRO such as the extensive qualifications and certifications used for state-of-the-art management and maintenance processes.

“The airlines’ primary function is to fly airplanes and provide the safest travel experience possible for the customer. It is not in aircraft maintenance. Air carriers are really good at being air carriers …. An MRO, on the other hand, is really good at being an MRO. So the business domain needs are different and have to be harmonized in some way so that results from projects are of mutual benefit” (Berry, 2013). The primary focus is different between an MRO and airline. Repair stations make money by delivering aircraft per schedule back to the airlines. Airlines earn revenue by flying airplanes with passengers, and or cargo, with quality aircraft.

Discussions are in place as to how an airline’s SMS can effectively interface and oversee all its operations including outsourced MROs and or in-house maintenance. And an MRO business typically has several airlines customers, so the discussion becomes further convoluted when addressing how an MRO can meet multiple airlines' SMS requirements that may have been implemented and interpreted subject to various airlines' enterprise models.

The question of how an airliner's SMS can interface with, and impact an MRO requires significant understanding. "If an MRO has invested heavily in lean processes to produce internal efficiencies, the operator's quality organization can impose un-optimized processes undermining the MRO's lean implementation. This can affect both parties' quality and production expectations" (Berry, 2013). By the same token, airlines that perform their own maintenance and repair under their own Part 145 certificate must develop an interface from the Part 121 side of their house to the Part 145 side.

The aircraft maintenance system is described as a complex socio-technical system. The four key aspects of aircraft maintenance that play a key role in are (Ward, et al., 2010):

1) Regulations
2) Other external bodies such as the manufacturer, customers, vendors and the airline.
3) Internal functions such as contract negotiation, personnel selection, personnel training
4) The production system that can include base, heavy, line, or light maintenance – all of which are supported by engineering, planning and commercial and quality departments

The interface and complexity discussion further supports the case that application of SMS into the MRO domain is misguided. Beyond the argument that a PRMS model fits MROs, and SMS does not, it can be argued that even if airlines' SMSs do fit and are applied to MROs, there can be an adverse impact on MRO lean processes that were set up to benefit the MRO, and the airline customer. In other words, SMS if pushed into the MRO domain, if not judiciously implemented, can negatively affect both domains' quality and production expectations. This calls for careful consideration when considering the interface between airlines and their MROs: "In moving to the SMS environment carriers now need to assess their own processes effects on vendors when engaged in outsourcing. By defining the interface between themselves and the MRO they will be able to address and standardize processes and controls" (Berry, 2013).

This research supports the position that SMS interface with an MRO can be adverse to both domains. It is argued that an airline/SMS interfacing with an MRO/SMS interface can be counter-productive to all parties, because SMS in the MRO domain in itself is a misguided concept. However, a PRMS model in the MRO domain will work, so it is the airline/SMS to MRO/PRMS interface that must be developed.

### 6.3.3 PRMS and MRO Regulations

In 2007 the FAA's Flight Standards service was drafting its planned implementation of SMS for repair stations. The Part 145 AC was entitled "Introduction to Safety Management Systems for Maintenance Organizations". The document is very similar to AC 120-92, "Introduction to Safety Management Systems for Air Operators" and in alignment with the FAA's move to comply with ICAO's SMS standards (Broderic & Pierobon, 2012).

Part 145 guidance was mostly identical to the air operator AC, other than the term "maintenance organization" in place of "air operator," where applicable. The close resemblance between the two documents was "by design," Don Arendt (FAA Manager of Flight Operations Safety Analysis Information Centre) told O&M, to ensure that FAA's multiple SMS efforts remain "aligned" as much as possible" (Broderick, 2007).

Based on their size, air operators are regulated under three rules - Part 91, 121 and 135. Part 121 applies to "majors" such as American Airlines, Part 135 applies to small regional carriers, and Part 91 is applicable to private individual operators. To accommodate these "Part" variances, SMS architecture is organized into subsets that divides the larger (and often more complicated) carriers from smaller ones. In 2010 there were 62 different major airlines in the

United States, including passenger carrying and cargo service providers (Swartz, 2014).

Unlike FAA rules for operators, U.S. regulations for MROs are not organized into such subsets, and as SMS is attached to the one Part 145 for MROs, by default, there is just one standard for all. This in itself is a significant issue for SMS/MRO discussion given that as of 2007 there were about 5,000 Part 145 certificate holders in the USA. About 28 percent employ fewer than five people, and 63 percent had fewer than 20 on the payroll. At the other end of the spectrum, about five percent had more than 250 employees. From a complexity-of-operations standpoint, nearly half the Part 145s had two or fewer ratings on their certificates, and 10 percent were working directly for Part 121 operators (Broderick, 2007).

With such numbers and diversity in the Part 145 domain, the concept in itself of applying a safety-centric architecture to a process-centric production risk environment seems unfeasible, and the argument that PRMS type architecture becomes more validated since it is domain-centric. A PRMS architecture is applicable to aircraft manufacturing and maintenance production risk, and is scalable to the many variances within those domains.

As of 2007 the agency planned to have SMS regulations for maintenance organizations in place by Jan. 1, 2009, which would align the agency's deadline with that of ICAO. Don Arendt acknowledged that while the air operators will "most likely get three years from the final rule's effective date to phase in SMS, maintenance organizations could get more time … The repair station world is behind the air operator world on this … There's not a lot published on repair station SMS".

An argument is that there are already more than enough data-gathering oversight programs, and thereby SMS – just another one – is redundant. To name a few these are the Continuous Analysis and Surveillance (CAS) program under FAR 121.373, Air Transportation Oversight System (ATOS), Flight

Operational Quality Assurance (FOQA), and Aviation Safety Action Partnership (ASAP). “FAA already has numerous safety management programs in effect that it cannot effectively manage now. How can it add another system and expect to manage it? Will it turn out to be another pile of data collected simply to collect with the rest? …. Some in the industry might suggest that all the safety management systems in the industry be scrapped at once and integrated into one huge safety management system. …. I don’t believe the mandate of the ICAO should extend to and include OEM product manufacturers, applicants and employers, and product or service providers in our industry” (Prentice, 2009).

As of 2014 there is not an FAA-mandated SMS for maintainers. Efforts continue and some MROs are using their interpretation of SMS as industry good practice. But their claim to SMS is often confused with personnel safety, not airplane safety – and is not primarily defined to address the primary function of the domain, that is, production risk.

## 6.4 PRMS Implementation, Assessment and Value

### 6.4.1 Introduction

Similar to SMS, PRMS can be approached by breaking it into bite-size pieces. As an MRO or manufacturer implements a PRMS they will find that many elements already exist within the organization. However, these elements may not be clearly documented, and a direct correlation between QMS and PRMS policies, programs, systems and procedures should be established. A methodology modelled after ICAO SMS gap analysis tools, can be developed to help design the PRMS and ensure thorough implementation. “A golden rule that becomes the foundation for success, just as it is for any other initiative within an organization, is that an organization’s executives must totally "buy in" and remain engaged throughout the process from development to implementation, by committing the time, resources, and effort it requires. Think about it. If the executives of an organization do not take “PRMS” seriously, how can they expect employees to embrace the behavioural changes that will be necessary for compliance? Executives can show their support by regularly scheduled briefings that communicate progress and maintain forward movement. For changes to be successful, it will be critical that senior executives motivate middle management, as this is where the accountability for change most likely falls. Lack of motivation coupled with a lack of accountability for forward progress at the middle management level will surely doom the project" (Cavalcante, 2012).

As with SMS, PRMS would most likely require organizational changes. Organizational culture develops over time, is dependent on the seniority of employees, rate of turnover, experience level of employees, training, administrative policies and consequences of production risk noncompliance, or lack of consequences for production performance noncompliance, as well as many other factors. Changing the corporate culture involves new habits that are repeated. Everyone must believe and take part in the process …... Changing the corporate culture involves new habits that are repeated until they become the new normal (Cavalcante, 2013).

For a PRMS to be successful it cannot simply be a copy of someone else's, or a manual that is put to one side and ignored. PRMS aims to proactively reduce the cost of the manufacturer's primary function (production) by mitigating production risks, and of supporting functions such as personnel incidents and injuries. PRMS must be created with inclusion of all organizational departments in order for it to pay for itself by minimizing production risks, escapements, and correlating events. In the SMS airline world it is argued that it is difficult to put a price on accidents that did not happen – so what should the SMS budget be? The monetary value of PRMS may be easier to quantify. A production risk can be extrapolated into a prospective internal production escapement that may be discovered immediately before the airline takes delivery of the airplane, in which case the manufacturer delays delivery to the airline while retrofit takes place. The airline may bill the manufacturer for lost revenue since the aircraft does not become operational, revenue-generating equipment per the airline's schedule.

Or, the production escapement may be external where several in-service aircraft are impacted and the manufacturer is liable for repairs under warranty at significant and very quantifiable costs. Aircraft manufacturers pay close attention to such actual and perceived events, and can use the data to establish the cost benefits of PRMS. Manufacturers have extensive records of the cost impact of production escapements, whereas airline in-flight accidents are rare – so airlines have a more challenging time to substantiate the monetary value of SMS. Safety risk costs are arguably qualitative, whereas production risk costs are quantitative. This emphasizes the difference between safety versus process-centric risk domains, and the misguided philosophy of applying SMS, rather than a PRMS, directly into the production environment.

### 6.4.2 Implementation

Majella McDonald comments that implementing an SMS, and conversely a PRMS takes time, effort and money. There is no “one-size-fits-all”, and each organization has its own vision, culture, customers, financial constraints, etc. She states that the most effective way to implement is through a phased process which provides for the enterprise to plan, develop, prepare their employees, implement, and conduct appropriate evaluation in practical consecutive steps. PRMS adapts to her four-phase implementation framework (McDonald, 2011):

#### Phase 1

1. Identification of the following:
    a. The accountable executive
    b. The person (or possibly group) responsible for implementing the PRMS
    c. Manager’s PR accountabilities; what managers are responsible for
2. Describe and document the system.
    a. PRMS components — general and/or specific to divisions
    b. Ensure employees are aware of these descriptions
3. Conduct a gap analysis
    a. Obtain an organizational baseline. Include a production culture assessment
    b. Determine how the organization will measure the success of the PRMS
4. Develop a PRMS implementation plan.

    a. Document how is it to be rolled out and the accountable person(s)
    b. Develop a realistic timeframe for the overall rollout plan
    c. Consider the human resource needs and financial implications of each phase
5. Develop documentation relevant to the enterprise's production policies and objectives.
    a. What currently exists and what is still needed (e.g., discipline policy, definition of terms, investigation policy, etc.)?
6. Develop and establish ongoing means for production communication.

    NOTE: This step may be inadvertently *overlooked or underestimated and the complete PRMS can suffer due to poorly developed — or nonexistent — communication channels.*
7. Determine and formalize divisional interfaces to share production information and learn from experiences.
8. Determine how all the PRMS data is to be collected and dealt with.
9. Commence development of production performance indicators and performance targets. Determine how the PRMS will be evaluated, both in terms of process evaluation as well as outcome evaluation.
    a. The process of implementation should be continuously evaluated to ensure it is being implemented as planned
    b. Outcome evaluation is the customary evaluation of a program — is it reaching the targets or goals we wanted it to?

### Phase 2

1. Implementation of reactive risk management processes.
    a. Document (and follow) event investigation processes conducted by formally trained personnel
2. Deliver training relevant to reactive risk management processes.
    a. Make all personnel aware of the processes, their own responsibilities, and how these reactive processes work together
3. Document all aspects relevant to reactive risk management tools for trend analysis
4. Develop formal communication to personnel of findings from reactive production events.
5. Determine PRMS software needs/packages available as well as current and future company needs.

### Phase 3

Implementation of risk management processes such as a confidential production reporting system, hazard identification and tracking system with feedback mechanism, regularly scheduled systemic production risk audits, and task analyses for all production-related activities.

1. Set up a risk-management working group to assess acceptable levels of risk.

2. Define the risk assessment tools and risk control mechanisms when an unacceptable level of risk has been identified.
3. Deliver training on these proactive and predictive production management processes.
4. Provide formal communication to personnel concerning these proactive and predictive tools including why they are beneficial.
5. Coordinate and maintain reactive production data synthesized with proactive and predictive production data (when this becomes available) from combined analyses tools.

**Phase 4**

1. Refine the production performance indicators and performance targets commenced in Phase 1 (Part 9).
2. Develop PRMS continuous improvement initiatives
3. Develop training and documentation relevant to operational production assurance.
4. Maintain and upgrade as needed the processes for production communication.

### 6.4.3 Assessment

When promoting SMS in the airline domain, the critical issues are how airline policy makers identify the key components of the system, how managers weigh the importance of its various dimensions and steps, and how employees are taught to evaluate the effects of these safety practices (Chen & Chen, 2012). Chen and Chen used scale development theory with Eigen values to assess SMS effectiveness, and a similar concept can be developed for PRMS assessment [Figure 6-1]. By identifying and mathematically weighting key factors, a quantified assessment can be established for PRMS effectiveness.

Another study to develop quantifiable structuring of critical success factors of airline SMS was completed by Yeuh-Ling Hsu, Wen-Chin Li and Kuang-Wei Chen (Hsu, et al., 2010). Here regulatory SMS components were listed from ICAO - Doc9858 SMM (2006); UK CAA – UK CAP712 (2002); Transport Canada – TP 1388IE (2002); FAA – OEP Vertsion 1.0 (2007); and Australia CASA – AC 172-01(0) (2005). These were aligned in the context of: Organization; Documentation; Risk Management; Quality Assurance; Safety Promotion; and Emergency Response. From here "components" such as organizational structure, management commitment, risk management capability, performance monitoring, and so forth, were arranged with "dimensions" and ranked in order of significance. By reviewing this model, a similar approach can be adopted as another consideration for PRMS assessment.

| | |
|---|---|
| | **Factor 1: Documentation and commands (DC)** |
| DC1 | Managers order clear commands for PRMS operation. |
| DC2 | The contents of PRMS manual are readily understood. |
| DC3 | System can precisely save, secure and trace the information. |
| DC4 | Establish an incentive system to reward the good PRMS perfomance. |
| DC5 | There is an intranet system to share the PRMS related information. |
| DC6 | Simple and unified standard for production behavior. |
| DC7 | Documents are reserved and updated in a standardized format. |
| | |
| | **Factor 2: Production promotion and training (PT)** |
| PT1 | Employees learn the concepts through training. |
| PT2 | Employees know how to execute PRMS through training. |
| PT3 | Employees upgrade the self-managed ability through training. |
| PT4 | Company provides training continuously. |
| PT5 | Employees construct the correct production attitude through training. |
| PT6 | Company holds PRMS promotion activities regularly. |
| PT7 | Company provides diverse training programs. |
| | |
| | **Factor 3: Executive management commitment (EMC)** |
| EMC1 | Top management participates in the PRMS related activities. |
| EMC2 | Management handles production risk issues following just culture. |
| EMC3 | Top management declares the determination to execute PRMS, even when the company finance is in the down cycle. |
| EMC4 | Top management declares commitment in formal documents. |
| | |
| | **Factor 4: Emergency preparedness and response plan (EP)** |
| EP1 | Employees acquainted with the plan. |
| EP2 | Employees are trained to execute the plan periodically. |
| EP3 | Company simulates the plan periodically. |
| EP4 | Company establishes the plan with clear procedures and individual responsibility. |
| | |
| | **Factor 5: Production management policy (MP)** |
| MP1 | Company develops the precise standard to monitor and evaluate the PRMS performance. |
| MP2 | Company continuously improves the PRMS performance. |
| MP3 | Company's internal reporting channel is highly accessible. |

**Figure 6-1. Scale Development of PRMS Evaluation**

### 6.4.4 Value

In 2011 the FAA estimated that the cost of SMS implementation to Part 121 air carriers would cost $721 million over 20 years for the initial SMS development, documentation and ongoing operations. The FAA also submitted that the resulting benefits in terms of avoided casualties, aircraft damage and accident investigation could exceed $1.14 billion (Lynch, 2011). This implies that SMS is cost effective, at least in theory.

In evaluating the prospective cost benefit of a PRMS implementation at a single manufacturing enterprise, the case study on Costs of Unsafety In Aviation provide some guidance (Cokorilo, et al., 2010). Authors of the research comment that their results are a qualitative tool that can be utilized for implementing a safety management system which has to be based on cost benefit analysis which balances accident probability and related costs against the costs of safety improvement measures. The research is based on a cost benefit analysis due to safety related benefits connected to aircraft accidents. By using a similar concept for PRMS, the benefit analysis can centre on PR related events connected to internal and external IP production escapements. This may be accomplished by providing costs to the PRMS Risk Assessment matrix to quantify the monetary impact associated with internal and external escapement events. By using historical data, a manufacturer can assign real values to estimate actual escapement cost impacts over time, and thereby establish the value of PRMS and the ROI projection. As an example, hypothetical $$ values are placed into the PRMS Cost Risk Assessment Matrix [Figure 6-2].

| IP Risk Probability (L) | | IP Risk Severity (S) (Place of IP error discovery / manifestation) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *External Escapement* | | *Internal Escapement* | | | | | | *No Escapement* | |
| | | A | | B | | C | | D | | E | |
| | | Airline / In-Service | avg. $ per event | Testflight / Delivery | avg. $ per event | Preflight | avg. $ per event | Downstream Production Line | avg. $ per event | Immediate Production Line | avg. $ per event |
| Frequent | 5 | 5A | $2,000,000 | 5B | $100,000 | 5C | $80,000 | 5D | $60,000 | 5E | $10,000 |
| Occasional | 4 | 4A | $400,000 | 4B | $80,000 | 4C | $60,000 | 4D | $40,000 | 4E | $8,000 |
| Remote | 3 | 3A | $100,000 | 3B | $60,000 | 3C | $40,000 | 3D | $20,000 | 3E | $6,000 |
| Improbable | 2 | 2A | $50,000 | 2B | $40,000 | 2C | $20,000 | 2D | $10,000 | 2E | $4,000 |
| Extremely Impossible | 1 | 1A | $30,000 | 1B | $20,000 | 1C | $10,000 | 1D | $5,000 | 1E | $0 |

**Figure 6-2. PRMS Cost Risk Assessment Matrix**

## 6.5 PRMS Maturity

As with SMS, just implementing a PRMS is not enough unless the PRMS achieves maturity in each organization to which it is applied (Fuentes, 2012). Factors are outlined to achieve risk management on a continuous basis that apply to a "PRMS" model. The ICAO/FAA SMS approach includes organizational structures, accountabilities, policies and procedures that transcribe to PRMS' 4 components and 12 elements. These follow the philosophy of Dr. James Reason's "Swiss Cheese" model (Reason, 1991), [Figure 6-3].

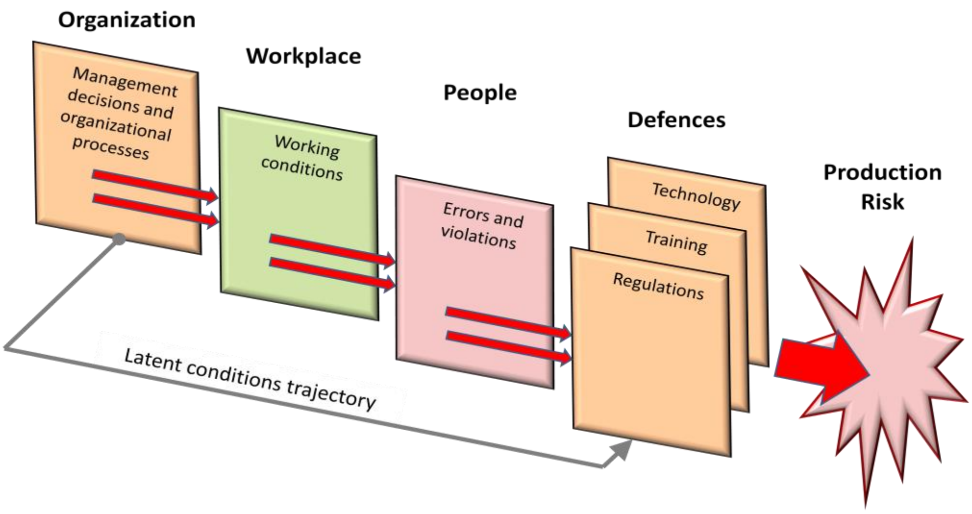



**Figure 6-3. Production Risk using James Reason's Swiss Cheese Model**

The manufacturing organization must integrate all components of PRMS architecture – but implementation is just the first step. It must run long enough for enough data to be gathered about production escapements, rate increases, organizational changes, personnel safety incidents, and any other conditions that increase production risk. The analysis, or measurement of “PRMS” effectiveness, can be achieved through two different types of data indicators: leading and lagging (Fuentes, 2012).

Leading indicators are the amount of events that must increase such as IP reports, and internal audits that need to be evaluated and closed. Lagging indicators are the number of events that need to decrease such as production discrepancy reports, airplane late deliveries, internal escapements, external escapements, and so forth. By measuring and monitoring these organizational processes, improving workplace conditions, containing unplanned events, identifying latent conditions and reinforcing defences, in conjunction with continuous feedback, the initial level of PRMS maturity should be recognized.

Top management support is essential for all aspects of a PRMS, including is a yearly assessment of how the PRMS is working compared to how it is designed on paper. “If the organization just approves their “PRMS”, but does not truly translate it into real life, the “PRMS” not only does not exist, but also becomes a false sense of security for the organization, creating expectations of improvement in “production” performance that are unrealistic. This type of organization is the typical company that creates what has been called the organizational accident, a tragedy that is directly the result of the actions and decisions of the organization and its management at all levels.” A change management practice is contained in ISO9001. It defines the quick response of an organization if it becomes aware of changes that can create new hazards, and it is already incorporated is manufacturers’ QMSs, Therefore, this area is already aligned for a PRMS-manufacturer arrangement.

To achieve PRMS maturity, all Components and Elements must be integrated in daily operations. “It takes time to work and show results but methodical implementation of “PRMS” concept will work to constantly improve “production operational risk” (Fuentes, 2012).

## 6.6 Further Considerations

### 6.6.1 Systemic SMS

As efforts around the world continue to implement or recommend SMS, discussion moves towards a holistic approach to decrease systemic breakdowns. The issue was addressed in 2012 by the International Federation of Airworthiness (IFA) at City University London. The dialogue was specific to the maintenance-flight operations interface, and how to better integrate the system. Discussion centred around fatigue of maintenance engineers, how effectively line maintenance communicates with the flight deck after the engineers work long hours, and the possibility of implementing a fatigue risk management system with AMO personnel (Pierbon, 2012).

This presents a challenge in the context of connecting two high-risk domains with one system. Flight operations deal with safety risk as the primary function, an AMO’s primary function is the work-task process/production function. This research paper shows the distinction between system-centric and production-centric primary functions and suggests the two systems are connectable but they are not the same, and an integrated one-system approach to be misguided.

If the fully integrated discussion was taken to an aircraft manufacturing enterprise, it may be argued that the airlines’ flight deck must have interface with the manufacturer’s AMO maintenance engineers who must also be subject to minimum rest periods, and then in turn the one-standard integrated system would require minimum rest periods for production line personnel and production-support engineers. The question becomes “how deeply into each others’ business domains should everyone be connected?” How integrated can a system be before it becomes impractical, burdensome and even dangerous? Results of this research differentiate between safety management and production risk management, and the limitations of overlapping these primary functions.

### 6.6.2 SMS Standstill

The affects of SMS on commercial operations is not well understood. Some argue that SMS is seen as another cost for safety problems that are low-risk, within the existing cost of doing business, and spending to save is a challenge to justify. Furthermore, the vehicles of regulatory implementation are under debate. In recent years regulators have been shifting from human factors management to SMS with focus not just on airlines, but with the aviation industry at large. EASA's umbrella Organizational Requirements (OR) and Authority Requirements (AR) operations rules allow for separate approvals for maintenance certification, production, design and flight operations. This provides for an organization to certify its operational functions along these segmented lines, rather than following ICAO's SMS organizationally-wide unified SMS certification. Given the concerns of having a fragmented SMS within an enterprise, the European Council (EC) in 2011 requested EASA to rewrite its rules without the umbrella provision (Burchell, 1 May 2011). Baines-Simmons also recommends against the fragmented umbrella approach. He argues that for SMS to be effective it should be embedded in organization – not bolted on. As of 2012 the EC was still in debate and falling further behind ICAO's intended implementation date of 2010.

The debate of how an SMS enterprise is aligned, and how it should be certified, is relevant to a PRMS. A large aircraft manufacturing company includes design, manufacturing and test flight operations. Many also provide MR&O services [Figure 2-1]. MR&O and manufacturing are task-driven functions that align with a PRMS. Flight test operations are safety-centric and therefore align with an SMS. Should SMS and PRMS functions be certified separately within the manufacturing enterprise given their differences? What would the overhead cost burden be to a separate SMS and PRMS implementation? Or – would the cost of a combined SMS/PRMS be less than or greater than separate implementations? Is it feasible for a manufacturer to expend resources to simultaneously implement an SMS and PRMS into the enterprise, or for effective implementation should they be implemented on different time schedules? If separated then the effect is "bolted on" which is contrary to some industry expert recommendations. This research does not seek to answer these cost questions – but raises them for further studies to address. Given the debates within regulatory bodies for implementing SMS with airlines, one can anticipate similar debates for the equally at best, if not more complex, aircraft production enterprises. And from a production perspective, one may argue that a PRMS is another cost burden to manage production risks that are already within the existing cost of doing business, and a PRMS ROI would not be substantiated.

### 6.6.3 SMS... Boom or Bust?

As of August 2013, ICAO and the Aviation section of the FAA continue with the intent to *mandate* SMS with Part 121 service providers, and EASA recently published its *proposed* SMS rules for repair stations. Conversation now addresses how U.S. domestic repair stations will cope with both EASA and FAA SMS rules, and if and when ICAO and the FAA will fully align with the EASA mandate. SMS is still a voluntary program for airlines and repair stations. It is essentially a sophisticated data gathering activity in the general area of flight operations, maintenance, human factors, and communications. Data is collected and analyzed so that problem areas can be defined and corrected before safety is compromised. Furthermore, SMS data is designed to be shared with other operators in the domain, and not protected with the voluntary and anonymous element of SMS. This is a point of resistance for operators opposed to SMS implementation.

As part of regulatory oversight, data gathering programs have been in place for many years such as FAR 121.373 CAS or CASP, the Continuous Analysis and Surveillance Program that was imposed for all Part 121 and some 135 air carrier operations. All major airlines must follow this for internal analysis of repeat discrepancy write-ups so that they can be analyzed, fixed, and not repeated, therefore enhancing safety. The data is also mandatorily provided to the FAA who use it as possible indicators of violations. But external to the airline organization, it is exclusive and proprietary to FAA.

A fully implemented FAA SMS is designed to mesh with the ICAO and EASA standards. The philosophy is to create a uniform system with which to compare safety standards and share statistics with each of the affected airline operators around the world. This is a noble concept but many feel it just won't work insofar as the sharing concept is concerned. The FAA also intends to provide data on accidents it has collected to the NTSB. This will probably include SMS data. The NTSB can contribute its expertise by looking closer at FAA collected data and examine accidents with more precision (Prentice, 2013).

The problem is that the SMS proposal so far does not include an employee confidential statement nor does it provide for the protection of proprietary carrier data. The fear in the industry is that critical proprietary operator safety information would be disclosed and would act as a deterrent to employee disclosure.

This discussion relates directly to a PRMS. First, even though primary airline operations pertain to public safety, imposition of data sharing across the operators is argued against due to prospective loss of confidentiality and possible use for litigation. And secondly it may be used for litigative purposes against the very airline providing the data. The primary function of MROs and manufacturing companies is production and therefore the “safety” argument to support implementation with these domains is not applicable. Furthermore, other than some data required for Part 25 regulatory oversight, much production data is closely held by the businesses in these domains and is used to optimize production rates that directly correlate to enterprise cost margins. The PRMS model aligns with a voluntary and anonymous production risk reporting system for internal organizational, but manufacturers would resist sharing it across national and international aircraft manufacturing companies and MROs who compete intensely with one another.

## 6.7 PRMS Liability

The FAA uses SMS as a methodology for controlling risk in airlines which leaves the attorneys concerned with prospective liabilities that an airline may encounter with an SMS program if an accident takes place. Questions are concerned with how evidence from SMS records of a reported violation or risk may correlate with the accident. However, Kent Jackson argues that SMS's voluntary disclosure programs avoid or minimize enforcement actions following self-discovered mistakes. Therefore SMS is not a liability (Jackson, 2008). Conversely, this paper proposes the same argument for a PRMS with manufacturers and aircraft maintainers.

A PRMS benefits the industry domain by having a strong data reporting and analysis capability that is used to reduce risk. For example, when a repetitive production non-conformance tag may, or does, correlate with production escapements, PRMS identifies margins to document the PR, and averts similar production errors in the future. PR is mitigated rather than accepted, and liability is avoided. This general risk control approach is already implemented in various ways, and documented and used as a function of aircraft QMS production operations. It is thus transferrable into PRMS architecture. Mechanics may see PRMS as leverage by upper management to document poor performance, but front line participants have to trust the system. The whole enterprise must not see it as a tool for management versus labour issues. Workers should participate with anonymity and without retribution, and the production culture must promote confidence that no one will connect the reports to personnel files.

Reporting in small organizations cannot work since everyone knows each other and it is difficult to create anonymity. This is not an issue for aircraft manufacturers that are large enterprises. If front-line production workers grade themselves and each other in an honest and open fashion, then PRMS can provide production risk management benefits, similar to pilots self-reporting programs where the airlines benefit from SMS.

Jackson researched case law regarding SMS records. He did not find reported aviation-related cases, or any disputes that were over SMS *record keeping*. The SMS cases he did find were in the maritime industry, and whether or not it is negligent *not to have an SMS program*: “The most interesting of these cases stemmed from the Oct. 15, 2003, crash of the Staten Island Ferry vs Andrew J. Barberi into a pier, which killed 11 passengers and injured many more. In a February 2007 ruling on liability, the federal judge specifically *noted the lack of SMS*: It is not surprising that the Staten Island Ferry's rules were not followed given the haphazard way in which they were disseminated. At the time the accident occurred, the internal rules were neither well understood nor effectively enforced. The Staten Island Ferry had no formal SMS. There was no single manual that was readily accessible to crewmembers. There was no mechanism to monitor who had received the procedures and at what time. And there was no system for ensuring that the rules were actually obeyed. … Instead, according to Capt. Gansas, "there was 'on the job' training and the policies and procedures were passed down from the senior captains and assistant captains" by word of mouth.”

Another argument in favour is: “…Effective management systems will, therefore, contribute to a decrease in insurance costs, improved reputation, and commercial success …” page 24 of Part A, EASANPA 2013-1 (Johnson, 2013).

Aimee Turner takes the opposite position regarding open data and information sharing: “...where even the smallest threat of prosecution exists, could a well-meaning attempt at boardroom level to encourage openness and information-sharing lead to a paper trail of ignominious discovery? Could the diligent documenting of a myriad of minor mistakes turn up as a prime exhibit in a criminal case? Is SMS simply masquerading as procedural jailbait?” (Turner, 2008).

Nick Sergi comments that “If you have an implemented SMS policy and have an occurrence you are more likely to violate a provision of insurance coverage, thus more liability. This does not seem right, but when you think about it and how insurance works, I think you will agree” (Sergi, 2010). The same conversation is applicable to PRMS.

SMS has become an industry standard for the aviation industry, and is in various stages of implementation with airlines around the world. As some form of it becomes regulated in the manufacturing and MRO domains, legalities of whether or not it is negligent for the domains not to have a version of an SMS, or PRMS must be addressed. In the future if a case is shown where a PR led to an external production escapement that in turn connected to an airline safety risk, and the manufacturer did not have a PRMS in place, it may be argued that the manufacturer is liable for *not* having a PRMS. Or, as Turner may say, a PRMS may become jailbait.

# 7.0 Current Status of FAA SMS Regulations

## 7.1 SMS Voluntary Pilot Project

In 2010 the FAA issued an extensive guide for SMS voluntary implementation activities: “Safety Management System (SMS) Pilot Project Participants and Voluntary Implementation of Service provider SMS Programs” (FAA, 2010). The guide contains expectations and procedures necessary to implement SMS by service providers. The document defines service providers … “as any organization providing aviation services …. including certificated and non-certificated aviation organizations, air carriers, airlines, maintenance repair organizations, air taxi operators, single pilot operators, corporate flight departments, repair stations, pilot schools, approved training organizations, and organizations responsible for type design and/or manufacture of aircraft.”

The implementation guide “is not mandatory and does not constitute a regulation. Development and implementation of an SMS is, therefore, voluntary. While the Federal Aviation Administration (FAA) encourages each service provider to develop and implement an SMS, these systems in no way substitute for regulatory compliance or with other certificate requirements”. It is similar in scope and format to the international ISO standards and is modelled after the safety, quality, and environmental management standards developed by organizations such as ISO, the British Standards Institute, Transport Canada, Standards Australia, and the International Air Transportation Association (IATA). It incorporates requirements of Annex 6, of the conventions of the International Civil Aviation Organization (ICAO), requirements of FAA Order VS 8000.367, Appendix B, and is aligned with ICAO’s SMS definitions.

The purpose of the guide is to assist service providers in developing and implementing an integrated, comprehensive SMS for their entire organization. The guide details a four phased process similar to that outlined in the ICAO Safety Management Manual (SMM) as outlined in ICAO Document 9859. This phased approach is employed by the U.K. Health and Safety Executive (HSE –

equivalent to U.S. OSHA) as a safety culture maturity model [Figure 7-1]. Furthermore, the guide provides a chart of how the implementation levels correlate to SMS components and elements [Figure 7-2]. The chart can be modified for PRMS implementation simply by replacing the SMS components and elements with PRMS components and elements.

The implementation guide recognizes that complete implementation of SMS at a large complex organization may take as long as three years. As the service provider completes each implementation level, that level is validated by the FAA. And upon successful completion of all levels the service provider receives a "Letter of Acknowledgement" verifying their participation in the SMS Pilot Project (SMS PP) and their associated accomplishments in the development of their SMS. The Letter of Acknowledgement is signed by the FAA, Director of Flight Standards Service.

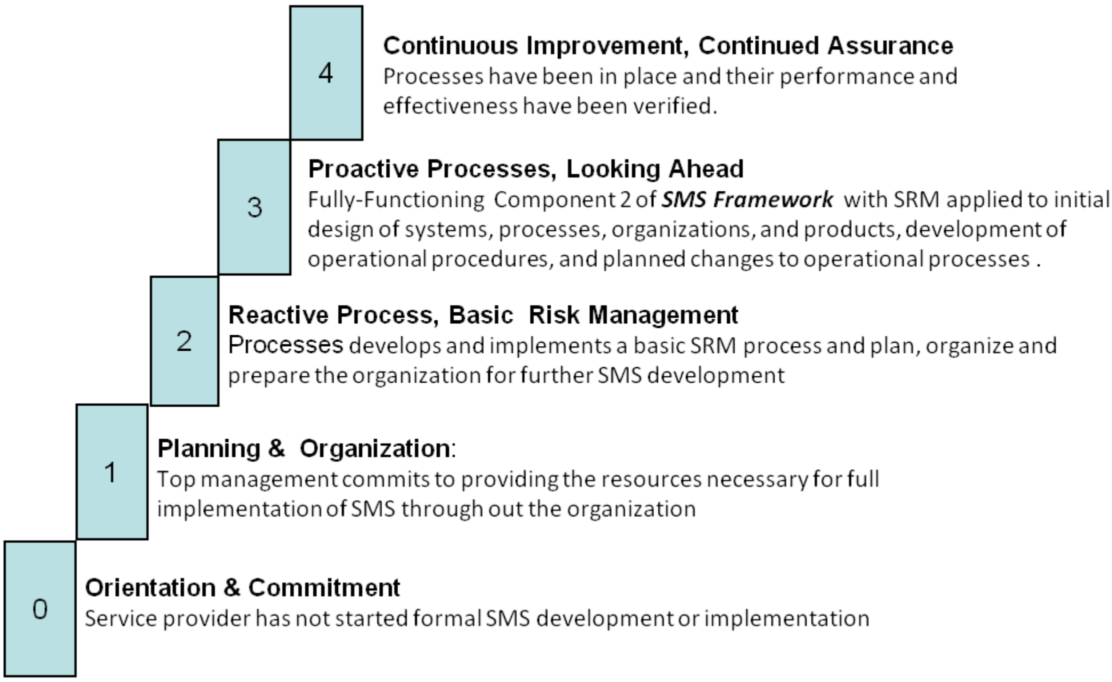



**Figure 7-1. SMS Implementation Levels**

| SMS Development Chart | | | |
|---|---|---|---|
| **Components, Elements and Processes should be completed by the indicated Level of Implementation** | **Implementation Level** | | |
| **SMS Framework Expectation** | **1** | **2** | **3** |
| Component 1.0 Safety Policy and Objectives | | X | |
| Element 1.1 Safety Policy | X | | |
| Element 1.2 Mgmnt Commitment and Safety Accountabilities | (*1) | X | |
| Element 1.3 Key Safety Personnel | X | | |
| Element 1.4 Emergency Preparedness and Response | | X | |
| Element 1.5 SMS Documentation and Records | | X | |
| Component 2.0 Safety Risk Management (SRM) | | (*3) | X |
| Element 2.1 Hazard Identification and Analysis | | X | |
| Process 2.1.1 System and Task Analysis | | | X |
| Process 2.1.2 Identify Hazards | | X | |
| Element 2.2 Risk Assessment and Control | | X | |
| Process 2.2.1 Analyze Safety Risk | | X | |
| Process 2.2.2 Assess Safety Risk | | X | |
| Process 2.2.3 Control/Mitigate Safety Risk | | X | |
| Component 3.0 Safety Assurance | | | X |
| Element 3.1 Safety Performance Monitoring and Measurement | | X | |
| Process 3.1.1 Continuous Monitoring | | X | |
| Process 3.1.2 Internal Audits by Operational Departments | | X | |
| Process 3.1.3 Internal Evaluation | | X | |
| Process 3.1.4 External Auditing of the SMS | | X | |
| Process 3.1.5 Investigation | | X | |
| Process 3.1.6 Employee Reporting and Feedback System | | X | |
| Process 3.1.7 Analysis of Data | | X | |
| Process 3.1.8 System Assessment | | X | |
| Process 3.1.9 Preventive/Corrective Action | | X | |
| Process 3.1.10 Management Review | | X | |
| Element 3.2 Management of Change | | (*3) | X |
| Element 3.3 Continual Improvement | | X | |
| Component 4.0 Safety Promotion | | | X |
| Element 4.1 Competencies and Training | | | X |
| Process 4.1.1 Personnel Expectations (Competence) | (*2) | | X |
| Process 4.1.2 Training | | X | |
| Element 4.2 Communication and Awareness | | X | |

*(*1) Level 1 - only comply with expectations 1.2 B) 2) & 3)*

*(*2) Level 1 - only comply with expectation 4.1.1 B) 1)*

*(*3) Level 2 - Implementation of 2.0 B) 2) a), b) & d) and 3.2, will be limited in level 2 by the lack of the system/task analysis process (process 2.1.1)*

**Figure 7-2. SMS Development Chart**

As of December 2013, 94% of major part 121 U.S. airlines have been or are participating in the voluntary program [Figure 7-3]. This is as a result of a now decade-old regulatory movement to implement SMS with airlines (FAA, 2013). With the knowledge that SMS would most likely be regulated at some point, airlines generally took the voluntary path so as not to be caught flat-footed when

SMS is mandated. On the other hand, repair and overhaul facilities are participating at a rate of 0.30%.

| | Major Airline Carrier | | General/Regional/ Charter Carrier | | Repair Station (MR&O) | | Flight School | | Training Center | |
|---|---|---|---|---|---|---|---|---|---|---|
| U.S. Region | 14 CFR Part 121 | | 14 CFR Part 135 | | 14 CFR Part 145 | | 14 CFR Part 141 | | 14 CFR Part 142 | |
| | # Providers | # Participants | # Providers | # Participants | # Providers | # Participants | # Providers | # Participants | # Providers | # Participants |
| AAL | 5 | 5 | 4 | 284 | 0 | 48 | 0 | 6 | 0 | 0 |
| ACE | 6 | 6 | 4 | 146 | 0 | 322 | 0 | 30 | 1 | 28 |
| AEA | 14 | 16 | 17 | 338 | 4 | 1106 | 0 | 104 | 0 | 8 |
| AGL | 15 | 17 | 12 | 252 | 2 | 325 | 2 | 266 | 0 | 8 |
| ANM | 7 | 8 | 7 | 252 | 0 | 325 | 0 | 84 | 0 | 38 |
| ASO | 18 | 18 | 11 | 304 | 4 | 795 | 1 | 98 | 0 | 19 |
| ASW | 6 | 6 | 14 | 217 | 3 | 677 | 0 | 86 | 0 | 36 |
| AWP | 12 | 12 | 17 | 333 | 1 | 994 | 1 | 119 | 0 | 13 |
| Total | 83 | 88 | 86 | 2126 | 14 | 4592 | 4 | 793 | 1 | 150 |
| ***Participation*** | ***94.32%*** | | ***4.05%*** | | ***0.30%*** | | ***0.50%*** | | ***0.67%*** | |

**Figure 7-3. U.S. Participation of Voluntary SMS Pilot**

AAL – Alaska Region: Appendix D

ACE – Central Region: Appendix E

AEA – Eastern Region: Appendix F

AGL – Great Lakes Region: Appendix G

ANM – Northwest Mountain Region: Appendix H

ASO – Southern Region: Appendix I

ASW – Southwest Region: Appendix J

AWP – Western Pacific Region: Appendix K

## 7.2 Final FAA Rule

The FAA published an SMS NPRM for Part 121 service providers in 2010. Since then, the industry returned comments, and after years of iterations and revised projected dates for the regulatory mandate, the FAA has set 05/12/2014 as the new projected date to register its final rule under the Federal Register:

**FAA Safety Management Systems for Part 121 Certificate Holders**

**Popular Title**: SMS for Part 121

**RIN 2120-AJ86**

**Stage:** Final Rule

**Previous Stage:** NPRM: Publication Date 11/05/2010; End of Comment Period 02/03/2011; Extended Comment Period 01/31/2011; End of Extended Comment Period 03/07/2011.

**Abstract:** This rulemaking would require each certificate holder operating under 14 CFR part 121 to develop and implement a safety management system (SMS) to improve the safety of its aviation related activities. A safety management system is a comprehensive, process-oriented approach to managing safety throughout an organization. An SMS includes an organization-wide safety policy; formal methods for identifying hazards, controlling, and continually assessing risk and safety performance; and promotion of a safety culture. SMS stresses not only compliance with technical standards but increased emphasis on the overall safety performance of the organization. This rulemaking is required under P.L. 111-216, sec. 215.

**Effects:**

- Regulatory Flexibility Act
- Information Collection

**Prompting action:** Statute

**Legal Deadline:**

- Final Rule: 07/30/2012
- NPRM: 10/29/2010

**Rulemaking Project Initiated:** 08/01/2010

**Docket Number:** FAA-2009-0671

**Dates for Final Rule:**

| Milestone | Originally Scheduled Date | New Projected Date | Actual Date |
|---|---|---|---|
| To OST | 03/16/2012 | 03/21/2012 | 04/12/2012 |
| Returned to Mode | | | 03/05/2013 |
| Resubmitted to OST/2 | | 07/12/2013 | 06/27/2013 |
| To OMB | 04/16/2012 | 02/05/2014 | |
| OMB Clearance | 07/16/2012 | 05/05/2014 | |
| Publication Date | 07/27/2012 | **05/12/2014** | |

**Explanation for any delay:** Unanticipated issues requiring further analysis

***Federal Register*** **Citation for Final Rule:** None

## 7.3 SMS Manufacturing and MRO Pilot Project

In 2011 the FAA started an SMS Manufacturing Pilot Project intended to run for up to 24 months. It was designed to support the FAA's ability to respond to the ICAO 2013 deadline for implementing SMS rules for manufacturers. The pilot project involves production approval holders (including at least two PMA holders) working with the FAA on developing SMS programs according to the rough guidelines developed by the FAA for purposes of the pilot project. Pratt & Whitney supported the pilot project that was the first Part 21 manufacturing pilot project in the world (Dickstein, 2011).

SMS with airlines took years of regulatory NPRMs and industry comments to reach its current state. Now the march is towards the other domains of the industry, with MROs and maintenance providers close in line. There are 88 Part 121 airlines in FAA jurisdiction, and even with a management system that is architected for safety – the primary function of airlines – it has taken the Federal Government and the FAA a decade to reach the 05/12/2014 final rule.

There are 4,592 Part 145 service providers under FAA jurisdiction. Given past history, it can be anticipated that the FAA will continue to encourage these MR&Os, along with manufacturers, suppliers, and so forth to participate in SMS on a voluntary basis. Maybe it will take the next ten years for MR&Os to move from a participation level of 0.3% to closer to 94.32% - and this would be the indicator that this domain has reached the threshold of a mandated "SMS" regulation. My research contends, however, that for such levels to be reached, the architecture must be domain-specific, it must be production process risk driven – not safety risk driven. To be effective it must fit the domain.

# 8.0 Conclusions

This research concludes that the overarching architectural philosophy, but not the specific lower-level details, of SMS can be applied to aircraft production and maintenance, as it has been applied to other industries including nuclear, rail and chemical. Just as SMS was tailored to these industries, it is has been tailored to the airline domain of the aviation industry. Field tests in this research attempted to take the airline SMS “as is” and apply it to the aircraft lifecycle at large, then to a restricted scope of the lifecycle, and then exclusively to aircraft production. It was determined that an unaltered “airline SMS” does not support an “aircraft lifecycle SMS”, neither does it support an “aircraft production SMS”. However, by modifying the detail level of airline SMS, the architecture is adaptable to aircraft production and maintenance operations. The modified model that emerges is “PRMS”.

Aircraft manufacturing and maintenance PRMS may be seen as a “cousin” to airline SMS. PRMS predictively and proactively identifies and prioritizes PR values for manufacturers and maintainers to mitigate risk within their domains. However, external PRMS escapements manifest in the airline environment. In such cases PRMS can interface with airline SMS data, even though PRMS and airline SMSs are independent systems with different primary focuses. Airline SMS is about airline operational safety risks – PRMS is about aircraft production and maintenance process risks.

SMS incorporates many existing airline QMS and ISO 9000/9001 facets, and similarly PRMS can be an extension of (or part of depending on implementation strategy) aircraft production and maintenance QMSs. PRMS differentiates from QMS in that it develops ATA-specific questions that focus on human factors at the production or maintenance lines, and applies the results to an ICAO-like Risk Assessment Matrix. Given that a manufacturer’s QMS is compatible to PRMS, as are airline QMSs and SMSs, the question arises about whether or not the investment of transitioning to PRMS architecture is cost effective. Mike Gamauf says “a good implementation should provide a systemic way to identify risks, and then manage them so as to not reduce the productivity of the organization (Gamauf, 2007). This research suggests a methodology to establish the PRMS ROI for manufacturers and maintainers.

The overarching reason that SMS is not applicable to the manufacturing or maintenance domains is that airline SMS is about safety risk, whereas PRMS is about process-driven risk. The primary domain functions, and thereby risk types are different. As evidenced in field tests the risk management system must be appropriately architected. Field tests show that by trying to identify a single-point-of-risk across all domains, the risk model does not provide adequate risk-type fidelity to focus on a specific domain. It is too general. However, Field Test 3 shows that when the risk model is tailored to one domain, risk in that domain can be assessed within the context of the ICAO risk management model.

This research concludes that an “umbrella organization” that meets ICAO’s organizationally-wide unified SMS certification proposal is not viable. The term “SMS” should be dropped from all domains other than airline operations. However the term “risk management” is applicable to all domains - SMS and PRMS are subsets of RM. An airplane lifecycle RM model is viable, and the manufacturing, airline and maintenance domains of the airplane lifecycle can be architected with the four components that SMS uses. Furthermore, each RM domain can be tailored to support an ICAO risk tolerability matrix. By taking this approach the domains are appropriately adapted to quantify their specific risk types, and by using a common tolerability matrix output, interfaces can be connected between the domain matrixes. This approach ensures an overarching risk management system supports domain-specific enterprises [Figure 8-1]. Findings from this research indicate that industry and regulators should modify their discussion to address how to connect an aircraft lifecycle risk management system via risk ICAO tolerability matrixes, rather than how to integrate a lifecycle Safety Management System.

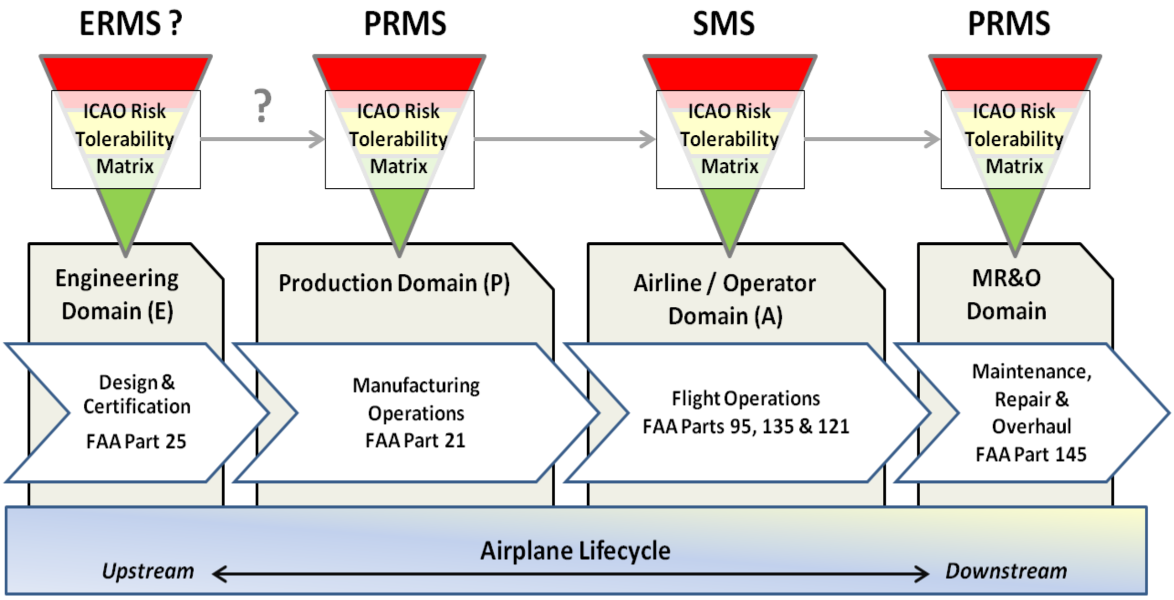



**Figure 8-1. Airplane Lifecycle Risk Management**

Results indicate that the research methodology is effective. By starting with the overall aircraft lifecycle, and using iterative field tests to bring the scope into a specific domain, the boundary around production (Field Test 3) is established. And with SMS arguably proven and accepted for Part 121 airlines, Field Test 3 aligns closely with the most current industry and regulatory dialogue that increasingly focus on the viability (or non-viability) of SMS in the production and maintenance domains. It is recommended that further research address development of the four components for an Engineering Risk Management System (ERMS), along with its associated Risk Tolerability Matrix. This would complete quantification of the airplane lifecycle risk management model using SMS-like architecture.

The most challenging aspect of this research is the dynamic nature of SMS. Since this research began, regulators wrote and rewrote the rules as to when SMS would be implemented, what SMS entails, and when it should and would be mandated as opposed to just recommended as industry practice. The global aviation industry is and has responded with various opinions that cover a wide spectrum of issues including the technical makeup of SMS, risk management theory, organizational theory, legality of regulatory mandates, liability of an implemented SMS, costs burdens and or benefits, data management and sharing, implementation, and the redundancy of SMS given the effectiveness of existing QMSs within domain infrastructures. All of these areas and more are research topics. Staying on track, exclusively to research the viability of SMS architecture in aircraft production, became a challenge given the amount of tangential subject matters under debate that connect to this study.

Secondly, introducing Safety Risk Management to a production IPT proved to be challenging. With production, safety is typically associated with personnel safety such as personal injury that can occur on the shop floor. During Field Tests 1 and 2, there was ambiguity when the focus shifted from airplane operational safety to the personal safety risk of workers. It was necessary use the terms very concisely: Safety in the context of SMS relates to aircraft operational safety, safety in the production system relates to personnel safety, and PRMS relates to production risk with personnel risk as a supporting PRMS function. Until these terms were clearly delineated, there was confusion at all levels of staff involvement as to exactly what or how to quantify safety when attempting to apply “SMS” to production. Research shows that this confusion of what “safety” means, when applying SMS to non-airline domains, is also playing out in the aviation industry at large.

When research began I considered SMS as applicable to all domains of the aircraft lifecycle. My thought was that each domain could have an SMS to support an integrated airplane lifecycle SMS, and thereby have a one-stop-shop to identify aircraft operational safety risk. I anticipated some minor data-type modifications to the four SMS components when applied to production – but not enough alteration to warrant a paradigm shift in my philosophy. As research unfolded it became increasingly clear that to support the various domains the primary risk intent has to be revised to be domain specific – to the point where the very term “SMS” became a misnomer for aircraft production and maintenance. Results indicate that an airplane lifecycle risk management system may be connectable through the use of domain-specific ICAO Risk

Tolerability matrices – but not via an overarching SMS. In 2008 the FAA inspector asked if SMS could be applied to manufacturing operations. This research concludes that it cannot be. However, an ICAO-style risk tolerability matrix can be developed that is domain-risk specific. The tolerability matrixes, not SMS, can be the common denominator across the aircraft lifecycle domains. The researcher proposes that further investigation of tolerability matrix interfaces take place.

In 2012 a small pharmaceutical research and development company began to develop Process Safety Management (PSM). It is observed that the company did not move towards fitting SMS “as-is” into their company, but took elements of SMS and tailored it to their business, and in doing so they focussed without confusion, on their primary risk factor, i.e. “process” (Goddard, 2012). In the same context it is argued by this paper that the application of airline SMS to production and maintenance domains is misleading, and management of production risk in the “spirit” of SMS should be named and architected for what it is, that is Production Risk Management System (PRMS).

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# Appendix A - Joint Planning Development Office

**Joint Planning and Development Office (JPDO)**
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January 28, 2010

Blake Gibbons
Commercial Airplane Group
5218 87th Avenue Court West
University Place, WA 98467

Dear Blake,

I want to personally thank you for your contribution in support of your Working Group and the Next Generation Air Transportation System (NextGen) initiative. I appreciate how demanding this role has been, and I realize that you are often carrying out this obligation in addition to your regular job responsibilities.

As we begin 2010, the Joint Planning and Development Office (JPDO) and, in particular, the JPDO Working Groups, have an ambitious agenda. There are important issues, some with far reaching implications for the future of aviation that need to be addressed. This is going to take cooperation, more hard work, and a lot of technical expertise.

I strongly believe that our Working Group members are more than capable of taking on these challenges.

The JPDO, through the NextGen Institute and the Working Groups, is unique among government and industry collaborations in that it not only delves into important subjects but is a long term project. In addition, it engages, at a working level, with the issues that are critical to the success of the NextGen mission. There is no precedent for this kind of involvement.

Again, thank you for your commitment, time, and enthusiasm as we move forward into the New Year.

Sincerely,

Charles Leader
JPDO Director

# Appendix B – Air Transport Association Chapters (ATA)

### AIRFRAME SYSTEMS

| ATA Number | ATA Chapter name |
|---|---|
| ATA 20 | STANDARD PRACTICES – AIRFRAME |
| ATA 21 | AIR CONDITIONING AND PRESSURIZATION |
| ATA 22 | AUTOFLIGHT |
| ATA 23 | COMMUNICATIONS |
| ATA 24 | ELECTRICAL POWER |
| ATA 25 | EQUIPMENT/FURNISHINGS |
| ATA 26 | FIRE PROTECTION |
| ATA 27 | FLIGHT CONTROLS |
| ATA 28 | FUEL |
| ATA 29 | HYDRAULIC POWER |
| ATA 30 | ICE AND RAIN PROTECTION |
| ATA 31 | INDICATING / RECORDING SYSTEM |
| ATA 32 | LANDING GEAR |
| ATA 33 | LIGHTS |
| ATA 34 | NAVIGATION |
| ATA 35 | OXYGEN |
| ATA 36 | PNEUMATIC |
| ATA 37 | VACUUM |
| ATA 38 | WATER/WASTE |
| ATA 39 | ELECTRICAL - ELECTRONIC PANELS AND MULTIPURPOSE COMPONENTS |
| ATA 40 | MULTISYSTEM |
| ATA 41 | WATER BALLAST |
| ATA 42 | INTEGRATED MODULAR AVIONICS |
| ATA 44 | CABIN SYSTEMS |
| ATA 45 | DIAGNOSTIC AND MAINTENANCE SYSTEM |
| ATA 46 | INFORMATION SYSTEMS |
| ATA 47 | NITROGEN GENERATION SYSTEM |
| ATA 48 | IN FLIGHT FUEL DISPENSING |
| ATA 49 | AIRBORNE AUXILIARY POWER |
| ATA 50 | CARGO AND ACCESSORY COMPARTMENTS |

### STRUCTURE

| ATA Number | ATA Chapter name |
|---|---|
| ATA 51 | STANDARD PRACTICES AND STRUCTURES - GENERAL |
| ATA 52 | DOORS |
| ATA 53 | FUSELAGE |
| ATA 54 | NACELLES/PYLONS |
| ATA 55 | STABILIZERS |

| | |
|---|---|
| ATA 56 | WINDOWS |
| ATA 57 | WINGS |

## POWER PLANT

| ATA Number | ATA Chapter name |
|---|---|
| ATA 61 | PROPELLERS |
| ATA 71 | POWER PLANT |
| ATA 72 | ENGINE - RECIPROCATING |
| ATA 73 | ENGINE - FUEL AND CONTROL |
| ATA 74 | IGNITION |
| ATA 75 | BLEED AIR |
| ATA 76 | ENGINE CONTROLS |
| ATA 77 | ENGINE INDICATING |
| ATA 78 | EXHAUST |
| ATA 79 | OIL |
| ATA 80 | STARTING |
| ATA 81 | TURBINES (RECIPROCATING ENGINES) |
| ATA 82 | ENGINE WATER INJECTION |
| ATA 83 | ACCESSORY GEARBOXES |
| ATA 84 | PROPULSION AUGMENTATION |
| ATA 91 | CHARTS |

# Appendix C – Production Culture Assessment

| | | Reporting | Just | Flexible | Learning |
|---|---|---|---|---|---|
| **1** | **Production Risk Reporting** | | | | |
| 1.1 | Existence of a PRMS reporting system | x | | | |
| 1.2 | Confidentiality | x | x | | |
| 1.3 | Existence of a program to inform employees and encourage them to use it | x | | | x |
| 1.4 | Percentage of employees who know about the Production Risk reporting system | x | | | |
| 1.5 | Existence of a process to use results to improve production risk | x | | x | x |
| 1.6 | Administration separated from the enforcement organization | x | x | | |
| 1.7 | De-identification of reports before dissemination within the organization | x | x | | |
| 1.8 | Use of metrics on organizational response to reports | x | | x | x |
| 1.9 | Frequency of analysis and reporting | x | | x | x |
| 1.10 | Percentage of reports that are responded to within nominal response time | x | | | |
| **2** | **Production Risk Organization** | | | | |
| 2.1 | Existence of a separate organization for production risk | | x | x | x |
| 2.2 | Published roles and responsibilities | | x | x | x |
| 2.3 | Published production risk policy | | x | x | x |
| 2.4 | Existence of production risk plan | | | x | x |
| 2.5 | Regular production risk updates, and update frequency | | | x | x |
| 2.6 | Performance metrics in safety plan | | | x | x |
| 2.7 | Percentage of employees who know about the PRMS organization | | | | x |
| 2.8 | Assignment of safety staff from within or outside the organization | x | | x | x |
| 2.9 | Percentage of employees who can correctly name their safety point of contact | | | | x |
| 2.10 | Assignment of production risk aversion points of contact throughout the organization down to the line worker level | x | | x | |
| **3** | **Training** | | | | |
| 3.1 | Existence of an ongoing Production Risk training program | | | | x |
| 3.2 | Types of Production Risk training | | | x | x |
| 3.3 | Percentage of employees who are up to date on recurring safety / production risk training | | | | x |
| 3.4 | Systemic tracking of safety / production risk within the organization | x | | x | x |
| **4** | **Senior Management Involvement** | | | | |
| 4.1 | Frequency of senior management presentation in production risk issues to the organization | | | x | x |
| 4.2 | Organizational levels of having personal contact with Senior Management regarding safety / production risk issues | | | | |
| 4.3 | Inclusion of the Production Risk Manager in the senior management structure | | | x | x |
| 4.4 | Production Risk manager responsibility for or involvement in financial decisions | | | x | x |
| 4.5 | Production risk criteria used for manager selection and evaluation | | | x | |
| 4.6 | Inclusion of a Production Risk manager's responsibilities in job performance reviews | | | x | |
| 4.7 | Staff with degrees or certification in Production risk | | | x | x |
| 4.8 | Staff assessed for role in achieving production risk goals. | | | x | x |

# Appendix D - Alaskan Region (AAL)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| Tatonduk Outfitters LTD | 121 | 2 |
| Peninsula Airways, Inc. | 121 | 3 |
| Northern Air Cargo, Inc. | 121 | 3 |
| Era Aviation, Inc. | 121 | 2 |
| Lynden Air Cargo, LLC | 121 | 3 |
| Coastal Helicopters, Inc. | 135 | * |
| Taquan Air | 135 | 1 |
| Temsco Helicopters | 135 | 1 |
| Ryan Air (Arctic Transport Servies, inc | 135 | * |
| Northern Air Services | 145 | * |
| | | |
| ** Waiting for Level 1 Orientation Meeting* | | |

# Appendix E - Central Region (ACE)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| Federal Express Corp. | 121 | 2 |
| GoJet Airlines, LLC | 121 | 2 |
| Endeavor Air | 121 | 2 |
| Trans States Airlines, LLC | 121 | 2 |
| United Parcel Service Co. | 121 | 2 |
| Air Evac EMS, Inc. | 135 | 3 |
| SpiritJets, LLC | 135 | 1 |
| Corporate Flight Management, Inc. (121 certification in progress) | 121 / 135 | 1 |
| Aviation System Standards FAA | 135 | * |
| EagleMed, LLC | 135 | 2 |
| Flight Safety International | 142 | 2 |
| | | |
| ** Waiting for Level 1 Orientation Meeting* | | |

# Appendix F - Eastern Region (AEA)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| CHAMPLAIN ENTERPRISES INC dba CommutAir | 121 | 3 |
| PIEDMONT AIRLINES INC | 121 | 2 |
| ATLAS AIR INC | 121 | * |
| BALTIA AIRLINES INC. | 121 | 1 |
| POLAR AIR CARGO WORLDWIDE INC | 121 | * |
| US AIRWAYS INC | 121 | 4 |
| COMPASS AIRLINES LLC | 121 | 1 |
| DYNAMIC AIRWAYS LLC | 121 | 1 |
| JETBLUE AIRWAYS, CORP. | 121 | 1 |
| ATLANTIC COAST AIRCRAFT SERVICES | 121 | 1 |
| SOUTHERN AIR INC | 121 | 1 |
| HYANNIS AIR SERVICE | 121 | 1 |
| MOUNTAIN AIR CARGO INC | 121 | 1 |
| SKYLEASE 1, INC. | 121 | 2 |
| Arcadia Aviation | 135 | 1 |
| Alpha flying/ Cobalt Air LLC | 135 | 1 |
| Aviation Services Unlimited | 135 | * |
| Charter Flight Inc. | 135 | 2 |
| Corporate Air, LLC | 135 | * |
| Hanger 6 FAA Flight Program | 135 | 1 |
| Flight Options | 135 | 2 |
| GAMA Charters Inc. | 135 | 2 |
| KEY AIR LLC | 135 | 1 |
| Keystone Med-Flight | 135 | 1 |
| Metropolitan Aviation LLC | 135 | 1 |
| North American Air Charter | 135 | 1 |
| Projet | 135 | 1 |
| Renaissance Jet, Inc. | 135 | 1 |
| STAT MedEvac | 135 | 1 |
| USAC Airways | 135 | 1 |
| TISMA | 135 | 1 |
| BombardierWest Virginia Air Center | 145 | 1 |
| KCI Aviation | 145 | 1 |
| Pratt & Whitney | 145 | 1 |
| Uniflight, LLC | 145 | 1 |

** Waiting for Level 1 Orientation Meeting*

# Appendix G - Great Lakes Region (AGL)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| PSA AIRLINES INC | 121 | 4 |
| CHAUTAUQUA AIRLINES INC | 121 | 2 |
| FRONTIER AIRLINES INC | 121 | 2 |
| REPUBLIC AIRLINES INC | 121 | 2 |
| SHUTTLE AMERICA CORP | 121 | 2 |
| MN AIRLINES LLC (Sun Country) | 121 | 2 |
| GULF AND CARIBBEAN CARGO INC | 121 | 2 |
| KALITTA AIR LLC | 121 | 2 |
| ABX AIR, INC | 121 | 2 |
| USA JET AIRLINES, INC | 121 | 1 |
| AIR WISCONSIN AIRLINES CORPORATION | 121 | 2 |
| UNITED AIRLINES, INC 121 | 121 | 4 |
| RYAN INTL. AIRLINES, INC. | 121 | 1 |
| RHOADES AVIATION, INC | 121 | 1 |
| BALTIA AIRLINES, INC (new certification) | 121 | 1 |
| Airnet System Inc. | 135 | * |
| Aitheras Aviation LLC | 135 | * |
| Executive Air Taxi | 135 | 1 |
| Executive Jet Management, Inc. | 135 | 3 |
| First Wing Aircraft Charter & Mgmt | 135 | * |
| Mercy St. Vincent | 135 | 1 |
| Midwest Aero Club, LLC dba Best Jets International, Inc. | 135 | 2 |
| NetJets Aviation, Inc | 135 | 4 |
| Oak Air, LTD. | 135 | * |
| Priester Aviation | 135 | 1 |
| Travel Management Co LTD. | 135 | 1 |
| Ultimate Jet Charters Inc. | 135 | 1 |
| Bowling Green State University | 141 | 1 |
| University of North Dakota JDO School of Aviation | 141 | 2 |
| Executive Jet Management, Inc. 145 | 145 | 2 |
| University of North Dakota JDO School of Aviation | 145 | 1 |

# Appendix H - Northwest Mountain Region (ANM)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| Alaska Airlines, Inc. | 121 | 3 |
| Horizon Air Industries, Inc. | 121 | 3 |
| Skywest Airlines, Inc. | 121 | 2 |
| Evergreen Intl. Airlines, Inc. | 121 | 2 |
| Great Lakes Aviation LTD | 121 | 2 |
| Empire Airlines, Inc. | 121 | 1 |
| Key Lime Air (121 certification in progress) | 135/121 | 1 |
| Air Methods HEMS | 135 | 4 |
| Alpine Air Cargo | 135 | 1 |
| Executive Flight | 135 | 1 |
| Global Aviation Inc. | 135 | 1 |
| Kenmore Air Harbor, Inc. | 135 | 1 |
| Premier Jets Inc. | 135 | 2 |
| Wings of Alaska | 135 | 1 |

# Appendix I - Southern Region (ASO)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| Delta Air Lines, Inc. | 121 | 4 |
| Miami Air International, Inc. | 121 | 4 |
| Falcon Air Express, Inc. | 121 | 1 |
| World Airways, Inc. | 121 | 1 |
| Seaborne Virgin Island, Inc. | 121 | 1 |
| Express Jet Airlines, Inc. | 121 | 3 |
| AmeriJet International, Inc. | 121 | 1 |
| North American Airlines | 121 | 2 |
| Sky King, Inc. | 121 | 1 |
| Florida West International Airways, Inc. | 121 | 1 |
| Centurion Air Cargo, Incl | 121 | 2 |
| Carribbean Sun Airlines, Inc. | 121 | 1 |
| Aerodynamics, Inc. | 121 | 1 |
| Spirit Airlines, Inc. | 121 | 2 |
| Western Global Airlines | 121 | 2 |
| Orange Air, LLC (new certification) | 121 | 1 |
| National Air Cargo Group, Inc. | 121 | 2 |
| Silver Airways Corporation | 121 | 1 |
| Aviator Services | 135 | * |
| Avantair, Inc. | 135 | * |
| Presidential Aviation | 135 | 1 |
| Professional Flight Transportation, Inc. (Windsor Jet Management) | 135 | 1 |
| Executive Air Services, Inc. | 135 | 1 |
| Florida Jet Service, Inc. | 135 | * |
| Airgate Aviation, Inc. | 135 | * |
| Sky Limo Corporation | 135 | * |
| Skylink Jets, Inc. | 135 | * |
| Execuflight, Inc. | 135 | * |
| AAR Airlift Group, Inc. | 135 | * |
| Aviator College | 141 | * |
| F & E Aircraft Maintenance | 145 | 2 |
| AAR Aircraft Services, Inc. | 145 | 1 |
| Propulsion Tech | 145 | 1 |
| Precision Turbines, Inc. | 145 | * |

** Waiting for Level 1 Orientation Meeting*

# Appendix J - Southwest Region (ASW)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| American Airlines | 121 | 4 |
| Southwest Airlines | 121 | * |
| American Eagle | 121 | 3 |
| Air Transport Inter. | 121 | 1 |
| Omni Inter. | 121 | 1 |
| Ameristar Air Cargo | 121 | 1 |
| Berry Aviation | 135 | 2 |
| Omniflight Hel. | 135 | 2 |
| Jet Solutions/Flexjet | 135 | 2 |
| PHI | 135 | 3 |
| 7-Bar Flying Service | 135 | 1 |
| C and S Aviation Ltd. | 135 | In que |
| Flying A Service | 135 | 1 |
| Mountain Aviation Enterprises | 135 | 1 |
| ERA Helicopters | 135 | 1 |
| Metro Aviation, Inc | 135 | 3 |
| Flying A Flight Service | 135 | In que |
| Flight Concepts, Inc. | 135 | In que |
| Chevron USA Prod | 135 | 1 |
| Memorial Hermann Life Flight | 135 | 1 |
| A/C Ducting Repair | 145 | 1 |
| ST Aerospace | 145 | 1 |
| Metro Aviation, Inc. | 145 | 1 |
| | | |
| ** Waiting for Level 1 Orientation Meeting* | | |

# Appendix K - Western Pacific Region (AWP)

| Voluntary SMS Pilot Project Participation Service Provider | Certificate Type | SMS Level |
|---|---|---|
| Aeko Kula Inc. | 121 | 2 |
| Aero Micronesia Inc. | 121 | 1 |
| Allegiant Air LLC | 121 | 1 |
| Hawaii Island Air Inc. | 121 | 1 |
| Hawaiian Airlines Inc. | 121 | 3 |
| Kaiserair Inc. | 121 | 1 |
| Mesa Airlines Inc. | 121 | 2 |
| Sierra Pacific Airlines Inc. | 121 | 1 |
| Swift Air LLC | 121 | 1 |
| TEM Enterprises Inc. | 121 | 1 |
| Virgin America Inc. | 121 | 2 |
| Vision Airlines Inc. | 121/135 | 1 |
| Aero Jet Services LLC | 135 | 1 |
| Arctic Air Services, Inc. | 135 | * |
| Aviation Concepts, Inc. | 135 | * |
| Blue Hawaiian | 135 | 2 |
| Dreamline Aviation LLC | 135 | * |
| Jack Harper | 135 | 1 |
| K&S Helicopters | 135 | 1 |
| Makani Kai Helicopters | 135 | 1 |
| Med-Trans Corporation | 135 | 1 |
| Pinnacle Air Charter | 135 | 1 |
| Reach Air Medical Service | 135 | 1 |
| Rogers Helicopters | 135 | 1 |
| Schubach Aviation (Tango Air Inc.) | 135 | 1 |
| Solairus Aviation | 135 | * |
| Superior Air Charter (JetSuite) | 135 | * |
| West Air, Inc | 135 | 1 |
| XO Jet | 135 | 1 |
| Able Engineering | 145 | 1 |
| Bombardier Tucson Air Center | 145 | 1 |
| Transpac Aviation Academy | 141 | 1 |
| | | |
| ** Waiting for Level 1 Orientation Meeting* | | |