공학박사학위논문

Roles of Safety Management System (SMS) in Aircraft Development and its Effective Implementation
-Focusing on Safety Risk Management-

항공기 개발 시 안전관리시스템의 역할 및 효율적인

적용방안에 관한 연구

–안전위험관리 중심–

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기계항공공학부

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이 논문을 공학박사 학위논문으로 제출함

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이원관의 공학박사 학위논문을 인준함

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Abstract

In the aviation industry, complex and advanced systems are constantly being developed and introduced. Although the reliability of aircraft has systematically improved as such advanced technology is further developed, the organizational and human factors that interact with those systems are the fundamental causes of the accidents [1, 2]. Due to the demand for a more efficient approach to system safety in order to cope with these changes, Safety Management Systems (SMS) is currently being investigated as effective, systemic management model.

Safety is the first priority in civil aviation, and so the International Civil Aviation Organization (ICAO) has introduced and mandated the use of SMS by airlines, airports, air traffic services, aircraft maintenance organizations, and training organizations. The aircraft manufacturing industry is the last for which ICAO has mandated the implementation of SMS. Since SMS is a somewhat newer approach for most manufacturers in the aviation industry, they hardly believe in the value of implementing SMS. A systematic approach of safety risk management, which is SMS from aircraft development phase, allows to minimizing the safety risks that may be missing during approval and certification process, and reduce tremendous redesign cost due to system failure after aircraft service-in.

This paper addresses the importance of SMS implementation in aircraft

manufacturing industry by identifying difference between SMS and Quality Management System (QMS) and analyzing aircraft accident cases. The severe hard/bounced and tail strike landings of accidents/incidents the McDonnell Douglas MD-11 aircraft can be analyzed as a case study. In this analysis, two analysis models can be used to identify the root causes and safety risk levels. The Human Factors Analysis and Classification System (HFACS) can be used for the root cause analysis, and the FAA Transport Airplane Risk Assessment Methodology (TARAM) can be used for risk assessment.

The analysis was conducted focused on safety risk management, and, we have verified that the management of safety risk characteristics that occur during early aircraft development stages and the systematic linkage that this safety risk has with an aircraft in service could have a significant influence on the safe operation and life cycle of the aircraft.

Failure to meet ICAO SMS standards will impair the ability to operate internationally, and ensuring compliance with the ICAO SMS standards could be a strong source of competitiveness in the global aircraft market. Therefore, lastly, this paper proposes effective and practical ways of implementing SMS which can be integrated with existing QMS in order to fulfill ICAO and FAA requirements. The integration of SMS and QMS is focused on safety risk management in aircraft manufacturing industries. Through the effective SMS implementation, manufacturing industries can expect practical value of safety improvement in safety risk management for

prevention of accidents and strong competiveness in global aircraft market.

Keyword : Safety Management System (SMS), Aircraft Manufacturing Industry, Design and Certification Processes, Human Factor Classification Analysis System (HFACS), Risk Management, Accident Prevention

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Chapter 1. Introduction

1.1. Background

The most aircraft manufacturing industries are faced with various environments. The following is some of aspects from safety management point of view.

① In aviation industry, more complex and advanced systems are newly and constantly introduced in a dynamic environment. In some of cases, these systems are outstripping the authority’s ability to certify it. Authority simply can’t keep up and appropriate approval standards are not available due to limited knowledge of new technology adopted in the aircraft development.

② As can be seen Fig. 1, the number of the world's jet fleet will increase more than double, which will reach up to 42,000 airplanes over the next 20 years [3].

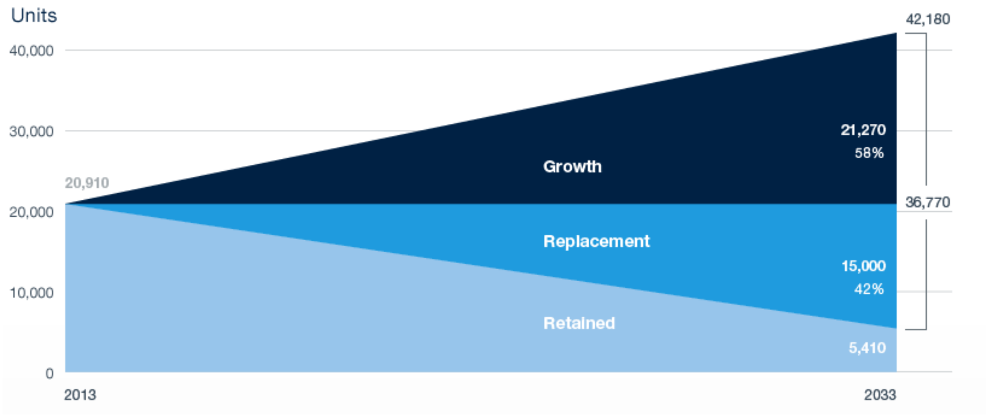

Fig. 1. Number of the World's Jet [3].

Fig. 2 [4] shows accident trends on commercial scheduled flights during the 2009~2013 periods. The number of accidents experienced annually was generally stable from 2009 to 2012, resulting in an equivalently stable accident rate (accidents per million departures). In consideration of the current trend of increasing air traffic volume in the United States, for example, it is easily predictable that the number of the accidents is going to be increased twofold as the air traffic volume is going to be increased twofold after 20 years from now.

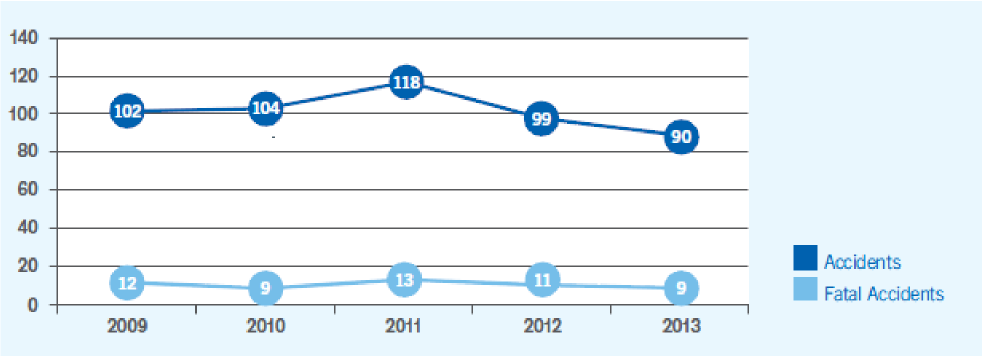

Fig. 2. Accident Trends 2009-2013 [4].

③ It is impossible to review and approve all the certification issues with limited authority's resource. Authority has relied on designee programs to help meeting its responsibility for ensuring that the aviation industry meets its safety standards.

One of nature of global aircraft market is working together more than two companies and/or two different countries with joint and/or outsourcing to have cost saving and global competitiveness. These require appropriate oversight program to ensure standards are meet.

④ Most aircraft manufacturing industry has management dilemma between "Protection" and "Production" which requires appropriate decision to make balance. For instance, when manufactures spend more resource on protection to ensure safety, such as aircraft devolvement could delay due to longer time on safety approvals and certification process, it can be cost much high. In case of delay of service-in for newly developed large aircraft, estimated delay cost is over 10 million UD$ a month [5-6].

On the other hand, excess allocation of resources for production could have an impact on the safety operations. By excessively pushing production, side, rather than ensuring more safety could results such as fleet ground due to system failure after service in and can ultimately lead to an accident. In case of B787 ground due to lithium-ion battery failure, it was estimated approximately 270 million UD$ for more than 3 months ground [7-9].

Due to the demand for more efficient safety management approach to cope with these complex environments, Safety Management System (SMS) is brought to attention as an effective and systemic management tool. International Civil Aviation Organization (ICAO) has published SMS rules that expanded its implementation to aircraft manufacturing industry recently. Under the current complex aviation manufacturing industry SMS is one of very effective safety risk management solution [5, 10-13].

SMS has adopted in various areas and research has been done in order to prevent accident. However, a few researches have been done for aircraft manufacturing industry. SMS is a somewhat newer approach to the most aircraft manufacturing industries, and because most of them already are implementing Quality Management System (QMS). And they believe that SMS is additional thus hardly see actual values of SMS.

Wolf [14] has presented why the Aerospace Industry should implement SMS through the examining case studies in the aspects of organizational behavior and safety culture approach. He has utilized accident cases of challenger, Gulf oil disaster, and Chernobyl to verify the organizational issues which lead accidents.

Fuentes [15] also, addressed the challenges of aerospace industry in order to effectively implement system safety practices in the point of organizational safety thinking and safety cultures. He has suggested general SMS activities for each different aviation segments, which are airline, maintenance organizations, flight training organizations, design and manufacturing organizations, air traffic control, and airports. For design and manufacturing organizations, he has addressed combine SMS requirements and existing QMS. However, it doesn't provides more details of "how" to be integrated.

According to the UK's Health and Safety Executive (HSE) research, it has been concluded that 59% of the main reason for accidents can be found at the design stages [16-17]. Kinnersley, S., Roelen [17] has validated approximately 50-60% of root cause of accidents was in design stage through the accident case study analysis; 18 aviation accidents, 6 nuclear accident, and 5 railways. They have addressed difficult to define relationships between aircraft life cycle and design aspects. While accident investigations are conducted with the aim of preventing similar accidents in the future, practical short-term solutions to identified problems are usually operational, training etc., rather than redesign, so the importance of design was not always highlighted in the investigation reports [17]. Also, They have suggested to prevent accident, best solution is to get the design right in the first place with respect to safety, because changes after the event rarely come cheaply or easily, despite the loss of life [17]. However, it was not cover how or what aspect to make design right in their paper.

1.2. Objectives and Scope of Thesis

In the aviation industry, complex and advanced systems are constantly being developed and introduced. Although the reliability of aircraft has systematically improved as this advanced technology is further developed, the organizational and human factors that interact with those systems are the fundamental causes of the accidents [1, 2]. Due to the demand for a more efficient approach to safety management in order to cope with these changes, SMS are currently being investigated as effective, systemic management models.

QMS is well known throughout the industry, and is also included in ICAO Annex 8 (Production Authorization), Annex 6 Part I (Maintenance Organization). It is also settled in the most aircraft manufacturing industry. In contrast, SMS was established somewhat later than QMS, and was systematically reflected on ICAO annexes for airlines, air traffic control, airports, maintenance organizations, and training organizations. The aircraft manufacturing industry is the last area for which ICAO has mandated the implementation of SMS.

Since SMS is a somewhat newer approach for most manufacturers in the aviation industry, they hardly recognize the value of implementation of SMS. Compared to SMS, Stolzer [18] verified that QMS does not specifically cover risk management and controls. QMS and SMS are similar in many ways, but there is a big difference. SMS is focused on safety, human and organization, and satisfaction of safety, whereas QMS is focused on product, service, and customer satisfaction [10-11].

SMS is intended to concentrically monitor safety performance, identify safety hazards, evaluate related risks, and manage risk effectively. In contrast, QMS is concentrated on compliance in regulations and requirements for satisfying customers' expectations and requirements on the contracts. QMS is focused on product and service with certain level of consistent quality for satisfying achievement and customer expectations.

QMS has independent Quality Assurance which allows utilization of feedback connection process, in order to guarantee supply of product and service which have no defects and are appropriate for its purposes and error free. On the other hand, Safety Assurance focuses on ensuring risk controls which meets safety objectives. Please refer to safety and quality relevant definitions in Table 1 [10-11].

Safety can be defined as freedom from those conditions that can lead to death, injury, occupational illness, and damage to or loss of equipment or property under stated conditions. Freedom from all hazardous conditions, which means absolute safety, is nearly impossible to achieve. Therefore, safety can be practically defined as maintaining a risk with an acceptable level in order to prevent accidents [10-11].

Reliability can be defined as the ability of the system to maintain its required functions under stated conditions for a specified period of time. Failure is not meeting required functions of a system, subsystem, component, or part to perform under specified conditions for a specified duration.

In addition to QMS, aircraft manufacturing industry is required to perform aircraft Functional Hazard Analysis as a part of the type certification process, in order to identify failure condition and improve failure rates. Failure of critical subsystem or component may result in unsafe conditions and/or acts. For example, a manufacturer has underestimated failure of the lithium-ion batteries on B787 aircrafts. It was assessed that the rate of occurrence of fire and/smoke due to battery failure would be about one in 10 million flight hours. However, that prediction for failure rate was significantly lower than the actual failure rate [19]. The first B787's battery's failure was observed at 52,000 hours of service. The fleet had been grounded for more than 3 months until redesign of battery was completed for safety purposes. This kind of unsafe condition could be prevented by more effective use of Functional Hazard Analysis methodologies. Under these circumstances, such improvement can reduce the possibility of accidents caused by component failures.

System safety is the application of engineering and management principles, criteria, and techniques to achieve an acceptable level of safety throughout all phases of a system. Achieving this definition of system safety is the primary objective of SMS [5-6]. It might be unsafe when system safety elements are not considered enough during design of reliability of product. For example, a windproof lighter may be highly reliable and safe when it is used under the normal conditions. However, when it is used next to flammable paint or a gas station, it is still very reliable but it is unsafe. Safety is always a primary concern, and the designers do everything possible to mitigate known problems. However, designers face with many different aspects besides safety, such as fuel efficiency and passenger comfort. Most systems currently have some mitigation to prevent unsafe acts such as redundant systems and safety procedures. However, no system is completely safe, and unsafe acts do occur. The area involving safety issue has broader meaning than the reliability. For prospective system safety, it is necessary to consider not only component failure but also system design, actual operating environments, human factor, and organizational factors.

Most of the aircraft manufacturing industries already have QMS and reliability program. Identification of hazards associated with organizational factors, including human performance within an organization is a paradigm shift to systemic safety management. By understanding systematic safety problems but not problems within the individuals which lead accidents to occur, the first step towards SMS is taken as effective systemic management solution to prevent accidents.

"An SMS cannot be built overnight". The first purpose of this paper is clearly address the reasons why aircraft manufacturing industry should begin to adopt Safety Management System through the case study analysis focus on Safety Risk Management aspects.

Accidents could be predicted and /or prevented if SMS has adopted and implemented? By identifying and managing a potential safety hazard from beginning of design stage, possibly can be reduced loss of human lives, system, equipment, properties after aircraft service in. Depending on how managed the safety risk characteristics brought up during the Type

Certificate process of the early aircraft design/development stages, and how systematically linked this safety risk after service in, it can have a significant influence on the safe operation and life cycle of the aircraft. Hazard identification and risk management must go beyond reliability and risks must be mitigated in the earliest possible stage.

The severe hard/bounced and tail strike landings accidents/incidents of the McDonnell Douglas MD-11 aircraft can be analyzed as a case study. In this analysis, two analysis models can be used to identify the root causes and safety risks. The Human Factors Analysis and Classification System (HFACS) can be used for the root cause analysis, and the FAA Transport Airplane Risk Assessment Methodology (TARAM) can be used for risk assessment.

Failure to meet ICAO SMS standards will impair the ability to operate internationally, and ensuring compliance with the ICAO SMS standards could be a strong source of competitiveness in the global aircraft market. Therefore, lastly, this paper proposed effective and practical ways of implement SMS can be integrated with existing QMS to fulfill ICAO and FAA requirements. The integration of SMS and QMS was focused on safety risk management in aircraft manufacturing industry. Through the effective SMS implementation, manufacturing industry can expect practical value of safety improvement in safety risk management to prevent accidents and to have strong competiveness in global aircraft market

1.3. Summary

This paper consists with 6 Chapters. The following Chapter 2 begins with undersetting concepts of safety management, managing hazard, safety data, and safety risk. Also, explained about theory of Practical Drift.

Chapter 3 introduces ICAO's expansion of SMS requirement mandating across the aviation industries. And then, SMS legislation progress for both Part 121 Commercial Air Carrier and aircraft manufacturing industry were analyzed. Through the understanding FAA's SMS rule making progress, it is possibly to predict the future global SMS legislation of the aircraft manufacturing industry. FAA has played significant roles in the international aviation legislation. Therefore, the SMS regulation established by the FAA, has a high possibility of being adopted as the international SMS regulation model in the future.

One of the natures of global aircraft market is that more than two companies and/or two different countries are working together. Therefore, activities of Safety Management International Collaboration Group (SM ICG) were reviewed to coordinate with other countries for effectively implementing SMS. To successfully enter the global aircraft market and maintain competitiveness, SMS could play significant roles.

In Chapter 4, the severe hard/bounced and tail strike landing accidents/incidents of the McDonnell Douglas MD-11 aircraft can be analyzed as a case study. In this analysis, two analysis models can be used to identify the root causes and safety risks. The Human Factors Analysis and

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Chapter 5 addressee findings of case study analysis and results of research. Also, this includes proposal for effective and practical ways of implement SMS which can be integrated with existing QMS to fulfill ICAO and FAA requirements in aircraft manufacturing industries. The integration of SMS and QMS was focused on safety risk management. Through the effective SMS implementation with integration of QMS, manufacturing industries can expect practical value of safety improvement in safety risk management to prevent accidents and strong competiveness in global aircraft market.

Lastly, conclusion and summary were made in Chapter 6.

Chapter 2. Safety Management

SMS is an organization-level top down approach to manage safety and risk. Through the analysis of safety data and risk mitigation, accidents and incident can be minimized [10-11].

The ICAO published the Safety Management Manual (Doc 9859) in 2006 for the better understanding on SMS, and the 3rd edition was published in 2013. The ICAO defines safety management as a system level that manages safety including the areas of organization systems, reasonability, policies, and process [10-11]. As can be seen Table 1 [20], from 2001, staring in the area of Air Traffic Service and Aerodromes, SMS requirements has been extended to across entire aviation industries such as airlines, aircraft maintenance organizations and training organizations. And recently ICAO annex 8 has revised and SMS requirement was extended into aircraft manufacturing industry. Also for the first time in 30 years, a new Annex 19 (Safety Management) was established in July of 2013. This annex includes basic guidelines for the safety management and governing by nations, and how product and service providers can establish SMS.

In order to comply with these ICAO SMS Standards, the aviation authorities of each member nation must establish a State Safety Program (SSP), and this is a basic program that manages safety and risk by setting up nationwide integrated safety objectives and safety indexes, etc. In connection with this, aviation industry also, requires adopt and implement

SMS as well.

Table 1. ICAO Annex and SMS requirement [20].

Safety Management SARPs for Service Providers			
Annex	Intended Audience	Denomination	Date Applicable
11	Air traffic services providers	Safety Management Programme	Nov, 2001
14	Certified Aerodromes	Safety Management Programme	Nov, 2001
2005 – Harmonization of Safety Management SARPs			
6, 11 and 14	A/C Operators & AMOs	SMS	Jan, 2009
2008 – 2nd Harmonization of Safety Management SARPs			
1	Training Organizations	SMS	Nov, 2010
8	Manufacturers	SMS	Nov, 2013
1, 6, 11, 14		SMS Framework	Nov, 2010

2.1. Concepts of SMS

2.1.1. Evolution of Safety Management

Fig. 3 [10-11] shows evolution of safety thinking. By improving technical factors such as safety equipment, efficient protective gear, as well as improvements in design, it has been possible to reduce the rate of accidents over the past 60 years. However, the improvements reached a limit at a certain point. By adding an additional method, which is a focus on systems' improvement, it was possible to improve even further. In other words, improvements were possible by intensive management of the quality system, human performance, and crew resource management. However, this stage also reached an improvement limit.

Historically, many people have believed that human errors occur due to individual characteristics or knowledge. However, a new point of view regarding human error is being suggested that errors are not just the product of inferior individual, but something that occurs naturally in all of us. In other words, since it is common for humans to make errors, the fundamental causes for humans making errors must be expanded to consider organizational factors.

Aviation throughout the world has been enjoying a steadily improving standard of safety over the last decades. This trend should not be allowed to stop or, more critically, not be allowed to reverse, particularly given the continuous growth in traffic. Each approach has led to significant gains in safety. However, even with these significant advances, we still have opportunities to take preventative action against accidents. The question for the aviation community is, "what is the next step?"

It is a general phenomenon that humans commit an error. Therefore, the root causal analysis on the making the errors should be extended to organizational factors. The term "organizational accident" was developed to describe accidents that have causal factors related to organizational decisions and attitudes [10-11]. SMS is a systemic perspective approach to improving safety at the organizational level.

This new approach is based on routine collection and analysis of data using proactive as well as reactive methodologies to monitor known safety risks and detect emerging safety issues. These enhancements formulated the rationale for moving towards a safety management approach.

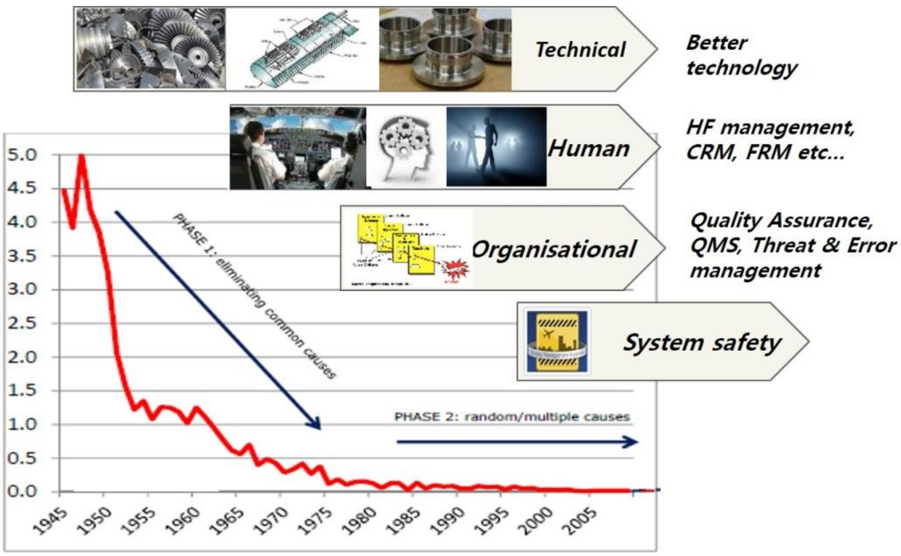


Fig. 3. Evolution of Safety Thinking [10-11].

2.1.2. Organizational Accident

Although the reliability is improved in systematic aspect through development of advanced technology, organizational and human factors interacting with those systems are being the fundamental cause of the accidents [1-2].

Organizational accident can be best understood through a building-block approach, consisting of five blocks are shown in Fig. 4 [11]. The top block represents the organizational processes. Typical examples include policy making, planning, communication, allocation of resources, and supervision. And there are two each pathway towards failure, downsides or deficiencies in these organizational processes.

One pathway is the latent conditions pathway which is the conditions may include deficiencies in equipment design, incomplete/incorrect standard operating procedures and training deficiencies. Latent conditions have all the potential to breach aviation system defences. Typically, defences in aviation can be grouped under three large headings: technology, training and regulations.

The other pathway originating from organizational processes is the workplace conditions pathway. Workplace conditions are factors that directly influence the efficiency of people in aviation workplaces.

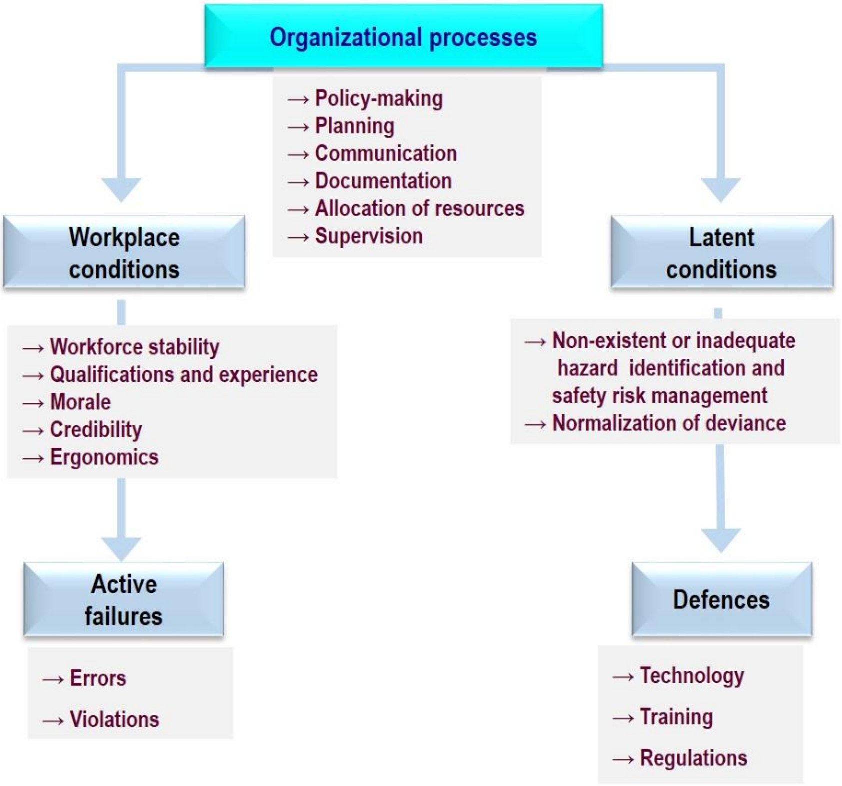


Fig. 4. Organizational Accidents [11].

2.1.3 SMS Components

SMS consists of 4 major components, and 12 elements as shown in Fig. 5 [11]. The key elements of the SMS concept which are new to certification process are Safety Risk Management and Safety Assurance.

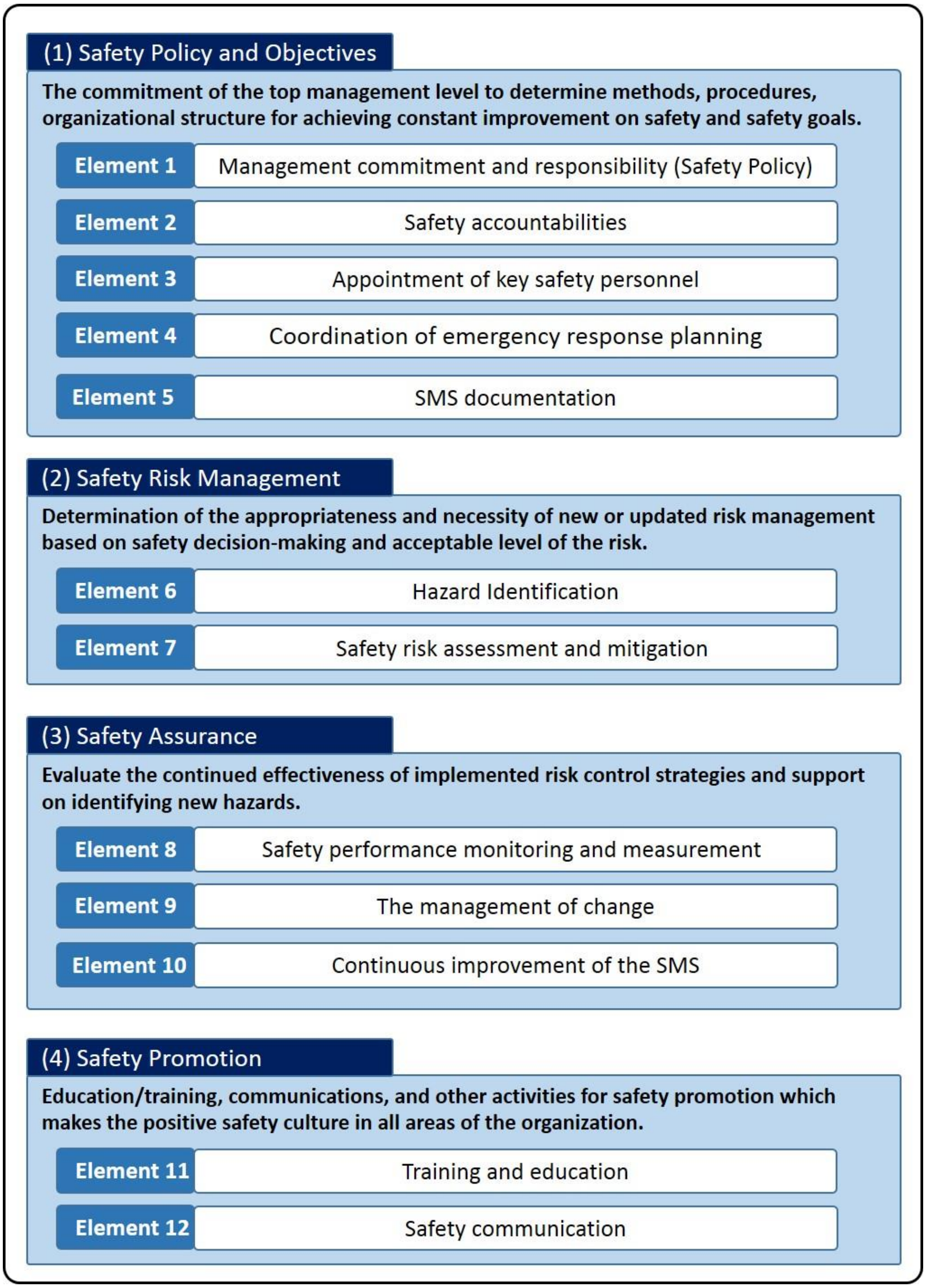


Fig. 5. Safety Management System Components [11].

2.1.4. Managing Hazards

Hazards are defined as existing or potential causes or factors that can result in the loss of human lives, system, equipment, properties, etc. [10-11]. Safety reporting systems, internal safety investigations, internal safety audits, safety surveys, safety studies, aircraft irregularity reports during maintenance, Flight Operational Quality Assurance (FOQA), and safety reviews containing hazard analysis are used as sources of data to recognize hazards.

The methods to collect safety information can be categorized into reactive, proactive, and predictive approaches, which are defined as follows in Fig. 6.

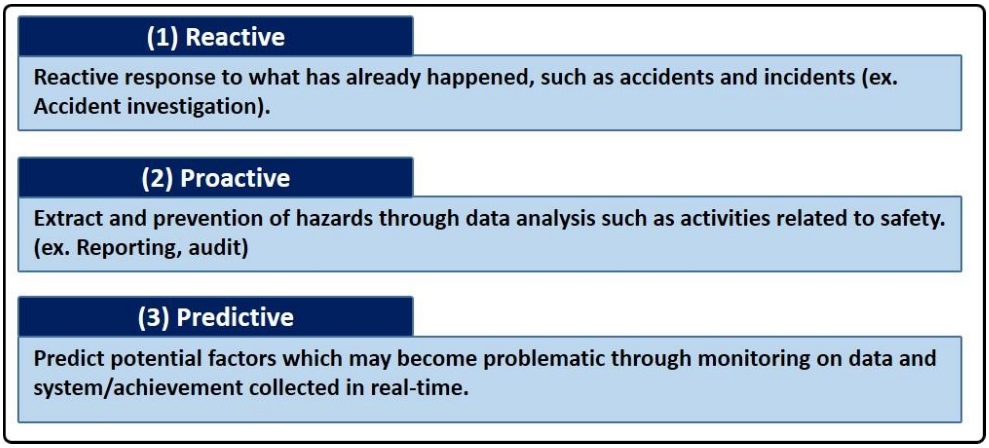


Fig. 6. Methods for Collecting Safety Information.

There are also many cases in which internal and external changes in the organization could cause hazards, and the most effective manner to recognize hazards can be through good monitoring and assessment of new process due to changes. This is referred to as “Change Management” in the

SMS framework [10-11]. The following are the most common changes that could produce hazards.

- Introduction of new equipment and technology
- Expected change in operation/work environment
- Increase in safety events or violations that cannot be explained. In this case, signs of danger are discovered in a new unpredictable situation, and abnormal conditions or operational conditions that were not previously recognized are present.
- In cases of where there is an excess of management parameters while periodically monitoring safety.
- In cases implementing new safety countermeasures or corrective action to reduce risk.
- Significant changes in organizational structure

2.1.5. Safety Data

For successful and effective SMS implementations, collection and utilization of safety data is the most important, and it is also the mandatory term which has to be activated [10-11]. In particular, safety data is the mandatory factor for hazard management. And it can be identified areas of vulnerabilities where risk is highest and requires priority for intensive management through the systematic safety data analysis. In other words, it is possible to set the priority on areas where inspection/audit is needed through data analysis. It also allows establishing risk based safety management system.

Indeed, analyzed safety data is also used for determining whether the system requirements are constantly met within SMS's safety assurance function. It is also used for analysis and verification of "efficiency" and "safety" of risk management in relation to the SMS.

Collection, analysis, and utilization of safety data is the key factor for successful and effective SMS implementation. Particularly, for safe decision based on data, it is significant to maintain accurate and quality of date [10-11].

2.1.6. Safety Risk

Risk is defined as the level of the risk that is measured according to the severity and probability of the potential for hazard. The type of risk mentioned in this paper is constrained to safety risks related to the operation of aircraft, and not financial or economic risks [10-11]. Risk management intends to measure, recognize, and analyze risk factors that can disrupt and threaten the operation of the organization in terms of maintaining an acceptable level of the risk as well as to eliminate and/or reduce such risk. Thus it allows for top management to make decisions that balance the allocation of resources according to the safety data and analysis [21].

Safety Risk Management (SRM) and Safety Assurance (SA) are key SMS functions that are part of the decision-making process outlined Fig. 7 [22-26]. Fig. 7 shows how the SRM and the SA functions are related to one another. SRM is a process that can be used to initially identify hazards and to assess risk. This risk analysis process includes an analysis of potential consequences of operation in the presence of the hazards that have been identified. Risk Controls have been developed to mitigate risk to an acceptable level, and it is thus determined to be acceptable to operate within these hazards.

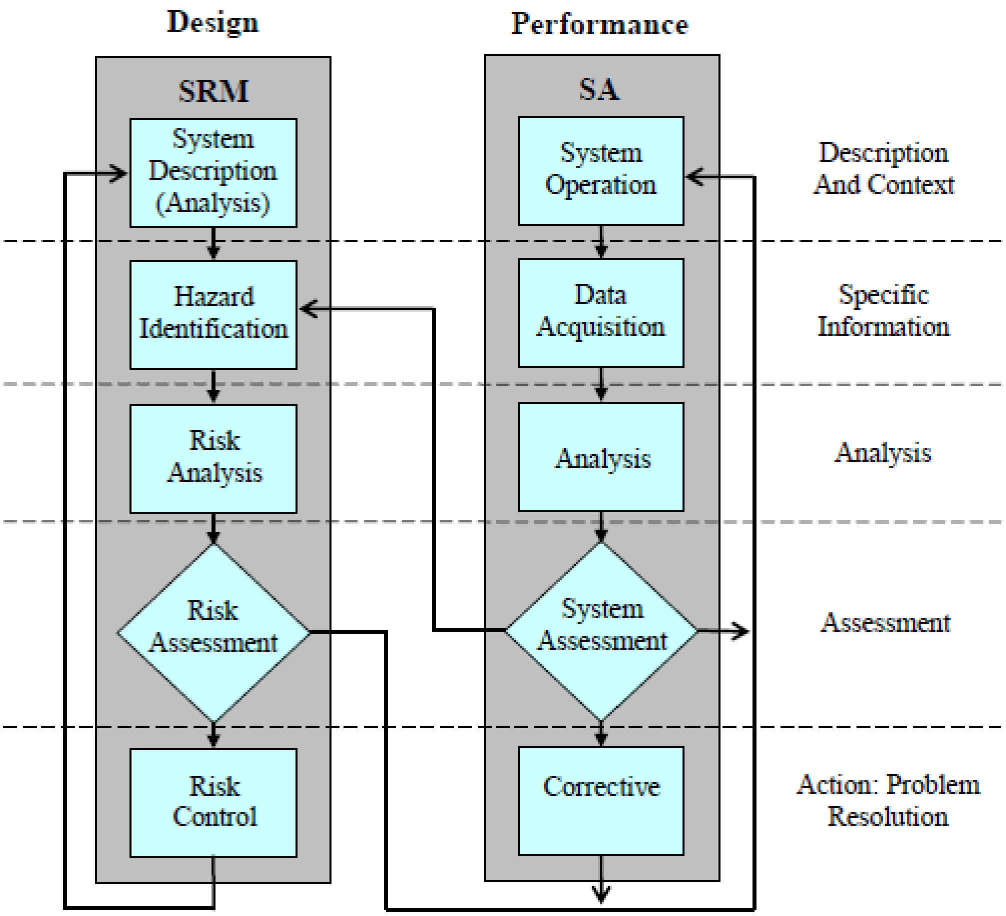


Fig. 7. Relationship between Safety Risk Management (SRM) and Safety Assurance (SA) [22-26].

After a system has been designed or redesigned using the SRM process, the new or revised system should be closely monitored by continuously using the SA process. The SA interacts with SRM to ensure that risk controls are practically in effect and that they continue to obtain their intended level of acceptable risk through continuous measurement and monitoring of the performance of the system.

As in SRM, safety data must be analyzed to engage in risk-based decision making. In the case of SA, several paths can be taken as a result of the decision-making process. If the data and analysis indicate that the system and its risk controls function at the intended risk level, the results are confirmed and management can now ensure the safe operation of the system.

In the case where the risk controls have not achieved their intended objective, action should be taken to correct the problem. In the case where the system is being used as intended and the expected results are not produced, the design of the system should be reconsidered by tracing the path back to the SRM process since doing so is an especially important role of the SA process [22-26].

2.2. Practical Drift

In 1994, a case of US Air Force F-15 fighter aircraft patrolling the no-fly zone in northern Iraq had shot down a friendly Army UH-60 Black Hawk utility helicopter is notable examples that can go wrong in highly complex system environments [27-29]. 26 people on board the helicopter lost their lives in this accident.

“Practical Drift” theory was developed by Dr. Scott Snook in the process to determine the root cause of this accident. A drift occurs in case of it was not responded in the field, or this was unable to comply with the planned procedure, even if any organization is planning to develop a procedure to handle routine and emergency situations [10-11].

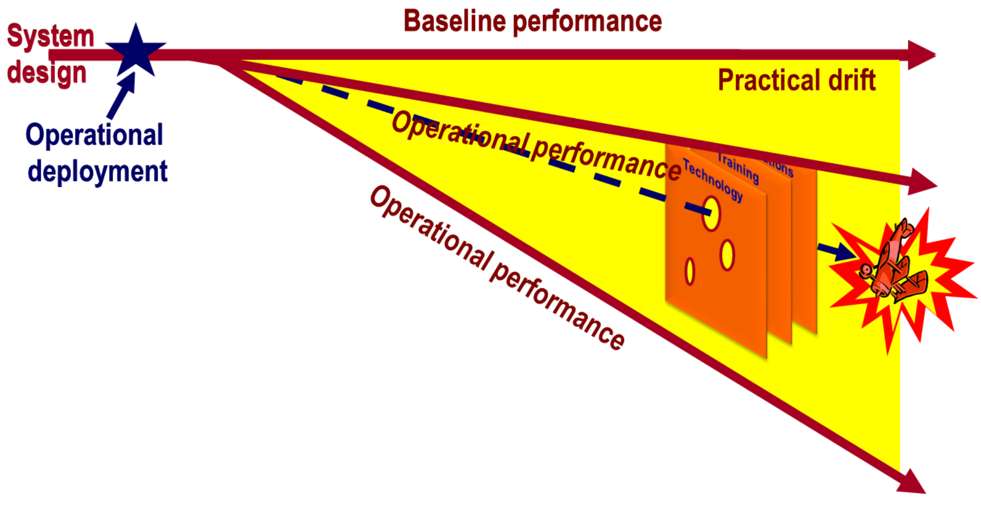


Fig. 8. Practical Drift [10-11].

As can be seen Fig. 8, a baseline is an ideal business form that could plan an initial system design. The initial system design is based on three fundamental assumptions to verify potential hazards, work limitations in advance.

- Technology : needed to achieve the system production goals is available,
- Training: people are trained to operate system/technology
- Regulation/Procedure: to control the system and the human activities

The most of time it is operated along with “baseline’ but later it will have deficiencies due to changes in regulatory and the real life operations environments. Another word, actual operation will drift or away from the directions that has planned. This refers to “Practical Drift”.

Even the most perfect system, “Practical Drift” can be occurred because of technology that does not always operate as predicted; procedures that cannot be executed as planned under certain operational conditions; and regulations that are not applicable within certain contextual limitations. Eventually, a drift from baseline is happened every day because system changes and interaction with these systems due to introduction of new additional systems.

Even, there is a drift, the system can be operated without major problems by applying local adaptations and personal strategies (beyond what the book says). However, it can be potential hazard and may lead the Practical Drift to depart too far from the expected baseline performance, to the extent that an incident or an accident becomes a greater possibility.

As explained in Fig. 6, capturing and analyzing the safety data on what takes place within the Practical Drift holds considerable learning potential about successful safety adaptations and, therefore, for the control and mitigation of safety risks.

A Practical Drift from baseline performance to operational performance is predictable in any system, no matter how careful and well thought out its design planning may have been [10-11].

As positive safety management approach, Practical Drift is likely to be found systemically in the initial starting of the system deployment. The closer to the beginning of the Practical Drift that the safety data can be systematically captured, the greater the number of hazards and safety risks that can be predicted and addressed, leading to formal interventions for re-design of or improvements to the system.

In addition to safety data, considering human interacting with system and organizational factors approach in parallel could expect greater effect for the control and mitigation of safety risks.

2.3. Comparison between SMS and QMS

SMS has systematically organized individual safety management programs which has been basically implemented, and is a somewhat new approach which consist with 4 components and systematized it, and is being developed into the requirement which most of the aviation organization requires recently.

In consideration of each safety management program which was already implemented, it is safe to say that some of the SMS is similar with QMS in many ways. However, SMS is focused on safety, human and organization "safety satisfaction", QMS is focused on the product, service, and "customer satisfaction". SMS is intended to concentrically monitor "safety performance" and identify safety hazards and evaluates related risks and effective risk management. In contrast, QMS is concentrated on compliance in regulations and requirements for satisfying customers' expectations and requirements on the contracts.

Also, SMS is designed to measure safety risk management and safety performance during production and service. Safety risk management process allows removal of risks, or maintaining balance between safety investment and service in order to satisfy safety performance, which all allows effective reduction and management of safety risk factors.

Aircraft manufacturing industries differ from other aviation industry businesses. They must deal with product lifecycles, such as requirements, design, testing and certification, production, support, and product retirement.

Another words, they have to manage both the safety of their fielded product as well as the processes which create the quality product.

Some of aviation industries that have well organized QMS, they still do not see values of SMS. ISO AS9100 which the aircraft manufacturing industry introduces and implements is one of the QSM, and is the international standard which applied QSM to aerospace industry.

"Safety" is important, but for the safety management, ISO AS9100 does not carry out safety and SMS components. Compared to SMS, AS9100 contains a very small portion of safety management and safety assurance. It also does not contain the sharing of safety information and safety development of SMS [18].

SMS and QMS mutually reinforce each other, and require mutual and extensive review and integrated utilization in order to achieve aviation safety goals. Quality goals and safety goals could sometimes conflict to each other, but they allow synergy and efficiency for safety management through the maintaining mutual reinforcement and integrated utilization.

QMS is focused on accurate and efficient conduction of certain duties for customer satisfaction. Safety management is focused on unsafe factors (hazards) which can cause damage on company. It also includes the measures to reduce chances of occurrence of damage on company and its influences. Table 2 [10-11, 30] shows summary of comparison between SMS and QMS.

Table 2. Definition Comparison Between SMS and QMS [10-11, 30].

SMS	QMS
Source: ICAO SMM Ed3	
• SMS is focused on safety performance. The objectives of an SMS are to identify safety related hazards, assess the associated risk, and implement effective risk controls. • SMS is to identify safety related hazards the organization must confront, and to control the associated risks. SMS is designed to manage safety risk and measure safety performance during delivery of products and services. The safety risk management process eliminates hazards or provides effective controls to mitigate safety risks by maintaining an appropriate resource allocation balance between production and protection to meet safety performance requirements.	• QMS is focused on compliance to prescriptive regulations and requirements, to meet customer expectations and contractual obligations. • QMS focuses on the consistent deliver of products and services that meet relevant specifications • A QMS provides consistency in the delivery of products and services to meet performance standards as well as customer expectations. The QMS also has an independent assurance function that utilizes a feedback loop to assure delivery of products and services that are —fit for purpose and free of defects or errors.
Source: IATA IRM Ed5	
• A systematic approach to managing safety within an organization, including the necessary organizational structures, accountabilities, policies and procedures. As a minimum, an SMS: → Identifies safety hazards; → Ensures that remedial action necessary to maintain an acceptable level of safety is implemented; → Provides for continuous monitoring and regular assessment of the safety level achieved; and → Aims to make continuous improvement to the overall level of safety.	• The aggregate of the organizational activities, plans, policies, procedures, processes, resources, responsibilities, and the infrastructure implemented to ensure all operational activities satisfy the customer's and the regulatory requirement. A controlled documentation system is used to reflect the plans, policies, procedures, processes, resources, responsibilities and the infrastructure used to achieve a continuous and consistent implementation and compliance.

Chapter 3. Analysis of SMS legislation progress in aircraft manufacturing Industry

3.1. ICAO Annex and SMS Requirements

The International Civil Aviation Organization (ICAO) published the ICAO Safety Management Manual (Doc 9859) in 2006 for the better understanding on SMS, and the 3rd version was published in 2013. The ICAO defines safety management as a system level that manages safety including the areas of organization systems, reasonability, policies, and process [10-11]

As can be seen Table 2 on the pervious Chapter, from 2001, staring in the area of ICAO annex 11 (Air Traffic Service), 14 (Aerodromes), SMS has been expanded to all of aviation areas. And recently it has been revised ICAO annex 8 and expanded SMS requirement to organizations of design and manufacture aircraft from November 2013. Also for the first time in 30 years, in July of 2013 a new Annex 19 (Safety Management) was established. This Annex includes basic guidelines for the safety management and governing by nations, and how product and service providers can comply with SMS frame works.

In order to comply with these Safety Management ICAO Standards, the aviation authorities of each member nation must establish a State Safety

Program(SSP), and this is a basic program that manages safety and risk by setting up nationwide integrated safety objectives and safety indexes etc. In connection with this, also, aviation industry requires adopt and implement SMS as well.

SMS is already implemented in other industries such as railway, nuclear reactors, medical etc. It could be a foolish thinking that SMS does not apply to the aircraft design and manufacturing industries.

To understand completed part 121 Commercial Air Carrier SMS related regulations, allow to predict the future legislation requirements of the aircraft design and manufacturing industry. FAA has played major roles in the international aviation legislation. Therefore, the SMS regulation established by the FAA has a high possibility of being adopted as the international SMS regulation model in the future.

3.2. FAA Legislation Progress

FAA is undertaking the transition to SMS in coordination with the international aviation community, working with ICAO to adopt applicable global standards for safety management. ICAO requires SMS for the management of safety risk in air operations, maintenance organizations, air traffic services, airports, and training organizations, and as well as for organizations that design or manufacture aircraft.

Among the aviation areas in the U.S, Air Traffic has fully implemented SMS for the first time in 2010 [31-32]. On the other hand, due to the diversity, size and complexity, and etc. of the US aviation industry, the implementation of SMS will be complicated. The FAA has made preparations to implement SMS from 2005, and for the Part 121 Operator’s (Commercial Air Carrier) final SMS rule was just announced on January 8, 2015 [31].

The following of this chapter, completion of SMS legislation for Part 121 Operator was reviewed at first, and then legislation progress for design and manufacture industry was predicted.

3.2.1. Part 121 Commercial Air Carriers

FAA has developed various SMS guidance in advance for industries to effective SMS implementation. Also, from 2007, they have operated pilot projects in order to encourage the voluntary participation of airlines, and collected feedbacks for reflecting into new SMS rulemaking for commercial air carriers.

The following Table 3 [31] is SMS guidance that FAA developed and distributed to the aviation industry in order to easy understand, establishment and implementation of SMS.

Table 3. SMS guidance that FAA developed and distributed to industry [31].

FAA Order		
1110.152	Safety Management System (SMS) Aviation Rulemaking Committee	Feb 2009
8000.369A	Safety Management System Guidance *(Supersedes FAA Order VS 8000.1)*	May 2013
8040.4A	Safety Risk Management Policy	April 2012
8000.367A	AVS Safety Management System Requirements	Nov 2012
8000.370A	Aviation Safety (AVS) Safety Policy	Apr 2013
8000.368A	Flight Standards Service Oversight (SMS Guidance for Flight Standards)	Dec 2012
8900.1	Volume 17 Safety Management Systems	Jan 2015
AC (Advisory Circulars)		
120-92A	Safety Management Systems for Aviation Service Providers	Aug 2010
120-92B	Safety Management Systems for Aviation Service Providers	Jan 2015
Gap Analysis Tool		
SMS Voluntary Program (SMSVP) - Air Carrier Gap Analysis Tool SMS Voluntary Program (SMSVP) - MRO Gap Analysis Tool		Jul 2014

In addition to, as can be seen Table 4 [31, 33-35], FAA has divided into 4 SMS implementation steps, for industries. As a results, 77 airlines were in the process of implementing SMS and a majority (58 airlines) of these were at level 1-2, 10 at level 3, and 9 airlines were in the final stages as of March 2014 [31, 33-35].

Table 4. FAA SMS Implementation Level [31, 33-35].

Level		Description
1	Planning and Organization	Top management commits to providing the resources necessary for full implementation of SMS throughout the organization. The organization completes **a gap analysis** to determine which elements in the SMS framework are not already being performed. Based on the gap analysis, the organization creates an SMS implementation plan to describe how the organization will close any identified gaps.
2	Reactive Process	The organization develops and implements basic **safety risk management and safety assurance processes**. These processes include information acquisition, processing, and analysis as well as the establishment of a **risk control and corrective action tracking system.**
3	Proactive Process	The organization has a functioning SMS. It applies safety risk management to the initial design of systems, processes, organizations, and products; the development of operational procedures; and planned changes to operational processes. This application of safety risk management includes analysis of systems and tasks, identification of potential hazards, and development of risk controls. Upon completion of level three, all required components are documented, demonstrated, and operational.
4	Continuous Improvement	Processes are in place, and their performance and effectiveness have been verified. The complete safety assurance process, including continuous monitoring, and the remaining features of the other safety risk management and safety assurance processes are functioning. A major objective of a successful SMS is to attain and maintain this continuous improvement status for the life of the organization.

In Nov of 2010, FAA made the Notice of Proposed Rulemaking (NPRM) in order to comply with the new ICAO SMS requirement that all the Part 121 Commercial Air Carriers requires to establish the SMS. Completed legislation was planned by September 2014, but it was made public in January of 2015 finally. According to this all part 121 airlines had to submit implementation plans, and these implementation plans have to be approved by the FAA before March 9, 2016, which is 18 months after mandating SMS requirements. Meanwhile, FAA has adopted SMS’s safety assurance functions to oversight industry’s SMS activities.

Full implementation of SMS was planned to be started on January 9, 2018, and there is a 3 year grace period. During this period of the time, airline could establish their own SMS depend on their complexity of organization and the business model. At the same time, FAA will evaluate and oversight whether each of their SMSs are implemented and fulfill requirement [22-26, 31].

According to FAA announcement [23], between 1998~2008 the aviation industry and the Federal government reduced the travel death risk to 83%. With full SMS implementation of Part 121 airlines, aviation safety management has been upgraded and it is expected 50% decrease goal will be achieved between 2010~2025. The costs for US airlines to training, develop system, and implement of SMS for the next 10 years is estimated to USD 224 million. The benefits of this investment are expected to be two fold the value of the investment.

3.2.2. Design and Manufacturing Industry

The FAR Part 21 (Certification Procedures for Products and Parts) was first established in 1964, and it is still the representative international certification model and is acknowledged as the global standard certification process [36-41].

FAA’s certification and approval workload is expected to grow due to the introduction of new technologies and materials. FAA Modernization and Reform Act of 2012 require the FAA Administrator to conduct an assessment of the aircraft certification and approval process. For the first time in 50 years, overall review and improvement of certification process including oversight areas are on-going to comply with strengthen SMS ICAO regulation and environmental changes of aviation industry [42].

The FAA already successfully completed SMS rulemaking for US airlines based on ICAO SMS frame work through the successful FAA SMS pilot project. During the rulemaking process, FAA has earned valuable experience and knowledge regarding effective SMS implementation. Based on the these knowledge and requirement of ICAO Annex 8 and 19, US SMS Aviation Rulemaking Committee (ARC) has made recommendatuons for reviewing Part 21 to comply with SMS requirements from the point of view of aircraft design and manufacture industries. SMS rule will be applied and expanded into aircraft manufacturing industries [12].

To establish SMS appropriate regulation for design and manufacturing industries in the US, SMS pilot project was also conducted from 2010 to 2012. The participants were selected from a variety of size and industries to consider all aspects of design and manufacture industry. As of April of 2014, the 6 pilot project participants are continuing to participate in line of SMS implementation steps. Among these companies, Boeing and Honeywell are expected to complete the SMS program in 2015 [5]. Detail results of pilot project will be discussed in the following sub-chapter 3.2.3.

Part 21 SMS NPRM is expected to be announced in January of 2016 and the final regulations that make mandatory SMS implementation will be made officially in June of 2017. The ARC [5] recommends the FAA and industry develop guidance for an SMS applicability threshold requiring an SMS for each organizations that—design or manufacture products (that is, aircraft, engines, or propellers); design or manufacture articles (TSO, PMA) whose failure could directly prevent continued safe flight and landing; or make design changes to a product through an STC, failure of which could directly prevent continued safe flight and landing.

According to the legislation plan for design and manufacture industry, in view of the Part 121 SMS implementation, within 6 months, which is by 2018, we could predict the industry required to establish SMS implementation plan. Full implementation will be expected within 3 years after finial rule.

Like Part 121 SMS implementation, FAA oversight methods will be changed by Risk-based /Performance based by adopting SMS’ s Safety Assurance function. Aircraft manufacturing industry could manage risk, more proactive ways while maintaining compliance with regulatory requirements. The manufacturing industry looks beyond compliance to identify potential risks that may or may not be covered by regulations, assesses the risks, and if necessary takes actions to mitigate those risks to create a safer operating environment

3.2.3. Overview of FAA Pilot Project

FAA Pilot Project for design and manufacturing (D&M) organizations, called Manufacturers Safety Management System (MSMS) was kicked off in 2010 and concluded in 2012. FAA participated with industries to build an enhanced safety management system using system safety principles. The key objective is determination of applicability of a SMS rule for design and manufacturing industry. FAA wanted to understand, through firsthand experience, how SMS can be applied to a diverse design and manufacturing industries to achieve full safety benefits and best use of oversight and industry resources. This includes detail gap analysis the SMS components and how they function in the aircraft design and manufacturing environment.

Initially 12 companies selected and 1 has decided to rescind participation due to other company priorities. 8 have completed a Detail Gap Analysis and 6 are continuous proceeded SMS pilot projects.

The participating design and manufacturing organizations varied in terms of size, production approvals, and products to provide a broad view of how SMS can be implemented in all aspects of the aviation industry. By including different types of organizations, the project team tried to learn as much as possible about the impact that SMS will have on them in order to guide future SMS rulemaking considerations.

The key categories included:

- Representation across design and production forms of approval: Production Certificate (PC), Part Manufacturer Approval (PMA), Technical Standard Order Authorization (TSOA), Type Certificate (TC), and Supplemental Type Certificate (STC)
- Representation from D&M industry o Large transport category aircraft manufacturer : Small aircraft manufacturer, Rotorcraft manufacturer, Large engine manufacturer, Small engine manufacturer, and Large PMA/TSOA manufacturer

Depending upon the size and complexity of the organization, the Detailed Gap Analysis was taken the full 6 months and longer in some cases. The following Tables 5 thru 8 [12] are results of detail gap analysis. Majority of rates have involved “Not Performed or Planed” in SMS’s components.

Table 5. Gap Analysis Results: Component 1. Safety Policy and Objectives [12].

	Not Performed	Planned	Documented	Implemented	Demonstrated
1.1 Safety Policy					
	25%	**50%**	**15%**		**12%**
1.2 Management Commitment and Safety Accountabilities					
	25%	**50%**		**12%**	**12%**
1.3 Designation and Responsibilities of Required Safety Management Personnel					
	38%	**50%**		**12%**	
1.4 Emergency Preparedness and Response					
	12%	**12%**	**25%**	**25%**	**25%**
1.5 SMS Document and Records					
	38%	**50%**		**12%**	

Table 6. Gap Analysis Results: Component 2. Safety Risk Management [12].

	Not Performed	Planned	Documented	Implemented	Demonstrated
2.1 Hazard identification and analysis					
	38%	**50%**			**12%**
2.2 Risk Assessment and Mitigation					
	62%	**38%**		**12%**	**12%**

Table 7. Gap Analysis Results: Component 3. Safety Assurance [12].

	Not Performed	Planned	Documented	Implemented	Demonstrated
3.1 Safety performance monitoring and measurement					
	50%	**38%**			**12%**
3.2 Management of Change					
	38%	**25%**	**12%**	**12%**	**12%**

Table 8. Gap Analysis Results: Component 4. Safety Promotion [12].

	Not Performed	Planned	Documented	Implemented	Demonstrated
4.1 Training and educations					
	38%	**50%**	**12%**		
4.2 Communication and Awareness					
	25%	**50%**	**12%**		**12%**

As can be seen Fig. 9 [12], overall results of gap analysis show 21% of all of the eight organizations' procedures and or processes were rated as Documented, Implemented , or Demonstrated to fulfill the SMS framework elements. 79% of the same organizations' procedures and/or processes were rated as Not Performed or Planned to fulfill the SMS framework elements. In many cases, organizations had gaps that resulted from not implementing existing procedures or processes systematically across the organization. For example, in the area of SRM, organizations generally have mature processes for identifying product hazards, but not organizational hazards.

Pilot project team expected that following the completion of the Detailed Gap Analysis, the organization will develop an Implementation Plan that will define the planned tasks and activities that are necessary for the organization to reach a fully functioning SMS.

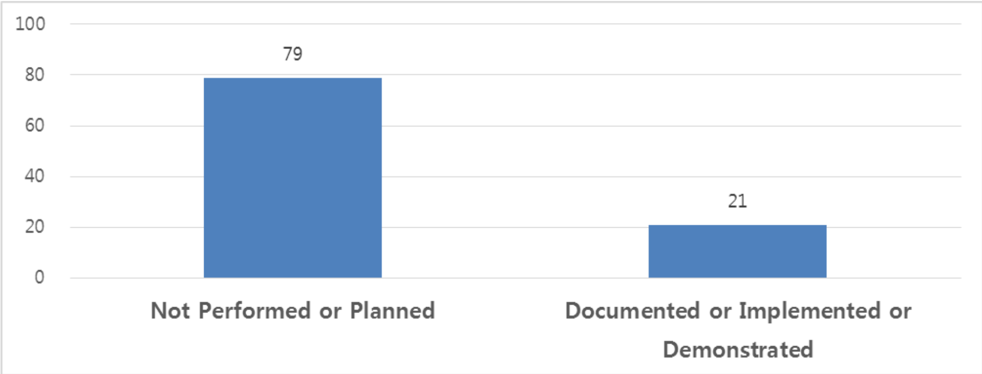


Fig. 9. Overall results of Detailed Gap Analysis Percentages of Processes and Procedures [12]

In conclusion of pilot project, the most manufacturing Industries do not carry out SMS components. The FAA should continue to work with design and manufacturers organizations on a case-by-case basis requesting FAA support to evaluate its SMS maturity before an SMS rule is published.

Also, pilot project team assumed that an FAA-issued SMS rule should be applicable to design and manufacturers, defined as organizations responsible for type design and/or the manufacturing of aircraft. This proposed scope for the SMS rule is directly in line with current ICAO requirements [12].

3.2.4. Safety Management International Collaboration Group (SM ICG)

SM ICG is an international group to support easier SMS implementation throughout the international aviation industry by understanding of the common principles and requirements for safety management. The purpose of SM ICG will be to harmonize SMS efforts, collaborate on topics of common interest, share lessons learned, and ensure the progression of SMS in a similar direction

Aviation authorities will benefit from collaboration and sharing of lessons learned and best practices. They could avoid duplication of efforts, to better share information, assist in developing robust and affordable safety management systems. Since many Aviation industry organizations own multiple certificate types in multiple nations, SM ICG's SMS requirement harmonization among regulators is very helpable activity.

The current core membership of the SM ICG includes the Aviation Safety and Security Agency (AESA) of Spain, the National Civil Aviation Agency (ANAC) of Brazil, the Civil Aviation Authority of the Netherlands (CAA NL), the Civil Aviation Authority of New Zealand, the Civil Aviation Safety Authority (CASA) of Australia, the Direction Générale de l'Aviation Civile (DGAC) in France, the Ente Nazionale per l'Aviazione Civile (ENAC) in Italy, the European Aviation Safety Agency (EASA), the Federal Office of Civil Aviation (FOCA) of Switzerland, the Finnish Transport Safety Agency (Trafi), Japan Civil Aviation Bureau (JCAB), the United States Federal

Aviation Administration (FAA) Aviation Safety Organization, Transport Canada Civil Aviation (TCCA), and the Civil Aviation Authority of United Kingdom (UK CAA).

Additionally, the Civil Aviation Department of Hong Kong (CAD HK), the International Civil Aviation Organization (ICAO), and the United Arab Emirates General Civil Aviation Authority (UAE GCAA) are observers to this group.

The SM ICG and its project teams continue have developed products to be shared with the wider aviation community. To support, each country's aviation authorities implements their SSP and Service Providers implement SMS in a more efficient manner, SM ICG has published the following recommendation to regulatory. The following is for their key point of State Safety legislative framework in line with the ICAO SSP Framework proposed in Annex 19 [43].

- Consult with your service providers from the beginning of the drafting process on the regulations and standards that relate to implementing an SMS for ensure service provider practices are captured and that they understand what needs to be changed.
- Specific guidance material may be needed based on type of operations, size, and complexity.
- Do not regulate through guidance material, but it is important to have useful guidance material to help both service providers and regulatory staff understand the intent and application of the regulation.

- The regulations do not have to mirror the ICAO framework word for word; the regulations should, however, address all safety objectives entailed by the requirements contained in the Annexes.
- Train your key personnel in SSP and SMS concepts before putting SMS regulations in place.
- Should prepared appropriate ability to provide adequate surveillance and confidence in the organization’s ability to manage the implementation process.
- Consider extending the assessment period to allow for effective implementation of all SMS-related systems.
- Require immediate compliance with all key processes, in which case the effectiveness of the processes must be demonstrated. However, it is unrealistic to expect an organization to have an effective SMS from its first day of implementation. Another approach is to phase in the implementation of the SMS processes and determine their effectiveness as each phase is completed.
- Develop procedures that allow for a phased implementation of an SMS. Remember: an SMS cannot be built overnight.
- The number of phases will depend on the type of organization, type of certificate held, the size and complexity of the organization, the type of operation (e.g., air operator's certificate, manufacturer).
- Provides a manageable series of steps to follow with clearly defined expectations for each phase; for continuous improvement through “lessons learned”; and for an effective implementation of SMS.

- The regulations must allow for SMS implementation in both existing service providers (who will be transitioning to an SMS) and new applicants (who may be starting an SMS from nothing).
- Coordinate other regulatory requirements within the State to avoid overlaps. This includes specific requirements that may be found in multiple areas of the aviation safety regulations (e.g., emergency response plans, quality assurance, risk management)
- Review international regulations for conflicts, compliance, and differences.

Chapter 4. Analysis Design Related Aircraft Accidents/Incidents

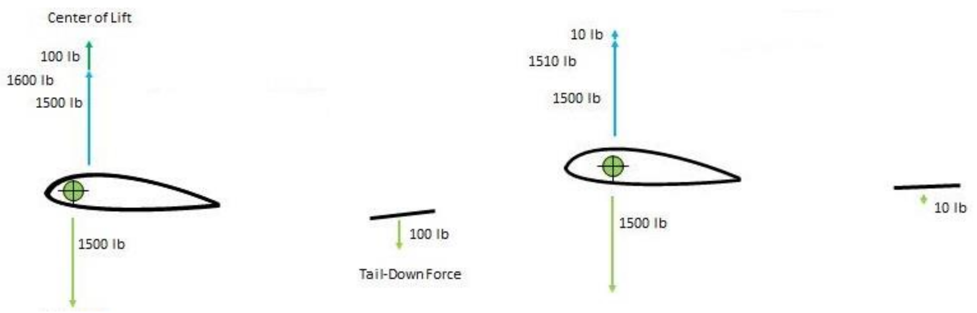
As can be seen Table 9, a total of 19 MD-11 severe hard/bounced and tail strike landings accidents/incidents were occurred between 1993 and 2013 [44]. In this paper, two analysis models can be used to identify the root causes and safety risks level with their investigation reports. The Human Factors Analysis and Classification System (HFACS) can be used for the root causal analysis, and the Transport Airplane Risk Assessment Methodology (FAA TARAM) can be used for risk assessment.

Table 9. List of accidents/incidents [44]

MD-11 Severe Hard/Bounced and tail strike landings			
	Date	**Location**	**Operator**
1	30 APR 1993	Los Angeles	Delta Airlines
2	19 AUG 1994	Chicago	Alitalia
3	21 JUN 1997	Honolulu	Garuda
4	31 JUL 1997	Newark	FedEx
5	2 2AUG 1999	Hong Kong	China Airline
6	22 MAY 2000	Taipei	Eva Air
7	20 NOV 2001	Taipei	Eva Air
8	7 JUN 2005	Louisville, Kentucky	UPS
9	23 MAR 2009	Tokyo	FedEx
10	3 JUN 2009	Urumqi	China Cargo
11	9 JUN 2009	Khartoum	Saudi Arabian
12	13 SEP 2009	Mexico City	Lufthansa Cargo
13	20 OCT 2009	Montevideo, Uruguay	Centurion Air Cargo
14	28 NOV 2009	Shanghai	Avient Aviation
15	27 JUL 2010	Riyadh, Saudi Arabia	Lufthansa Cargo
16	22 SEP 2010	Kabul, Afghanistan	World Airways
17	13 OCT 2012	Sao Paolo, Brazil	Centurion Air Cargo
18	25 JAN 2013	Denver	FedEx
19	24 NOV 2013	Sao Paolo, Brazil	Lufthansa Cargo

4.1. Accidents/Incidents Review

MD-11's center of gravity was designed to be located further after than other commercial aircraft to improve fuel efficiency. As can be seen Fig. 10, when the CG is at the after limit, the tail-down force is reduced. This means that the total weight to be lifted is reduced. In other words, after CG requires less lift but provides less stability. This has resulted in sensitivity in the control column. This type of design, which is referred to as “Relaxed Stability”, is commonly applied to fighter jets and is the first attempt to large commercial aircraft. This could result in excessive control during recovery due to the oscillation of aircraft in case of bouncing or a hard landing and can also serve as a factor that makes the situation more serious.



Forward CG **After CG**

Fig. 10. Comparison between Forward CG and After CG

MD-11 is essentially a stretched DC-10, with winglets. Significantly, the designers increased the operating weight and the length of the aircraft, without re-engineering the wing and rudder. As a result, the aircraft has rather slow roll and yaw responses to control input at low speeds, i.e., on short finals and during the landing flare [45].

After investigation of FedEx MD-11 lost at Newark, NY, in July 1997, the National Transportation Safety Board (NTSB) in August 2000 issued a brace of recommendation, calling for new flight control software to decrease the airplane's pitch sensitivity and, more significantly, a study of the aircraft's landing characteristics with a view to improving certification criteria. However, the study was never done.

The NTSB has determined that the MD-11's controls were more sensitive than those of other airplanes, especially at low speed and altitude [46-48]. In contrast to other commercial aircrafts, the MD-11 requires a unique landing technique to compensate for the pitch up. This requires for the pilot to first push the control yoke as soon as the aircraft touches down and the spoilers extend, and then to pull the control yoke as soon as the auto brake is applied in order to softly lower the nose of the aircraft.

In most of the cases, the unexpected hard touchdown had made pilots to overcompensate, resulting in tail strike. Pilots, who are aware of this, are also trained to know that a tail strike can easily follow a hard landing. They are also particularly aware of any pitch up on landing. Repeated botched landings can result in a hazardous bounce, wing fractures and sometimes even rolling on the runway, such as FedEx accidents occurred in Newark and Narita. Other examples include China Airlines accident occurred in Hong Kong, and Lufthansa Cargo accident occurred in Saudi Arabia. There have been many other landing accidents and incidents, but let's review couple of accidents where the plane ended upside down.

FedEx MD-11 freighter landed in good weather at Newark, in July 1997, but bounced on landing, came down hard on the main landing gear, broke off the right wing and was wrecked. The two-man crew got out alive and unharmed. The NTSB [46] determined that the probable cause of the accident was "the captain's overcontrol of the airplane during the landing and his failure to execute a go-around from a destabilized flare."

What resulted was pilot-induced oscillation (PIO). As NTSB [46] explained: "Considering the captain's three significant elevator control inputs in sequence, it is apparent that after the first destabilization of the landing flare (from the captain's nose-down input at 17 feet above ground level), each of the succeeding nose-up/nose-down elevator inputs resulted from the captain's attempt to correct for the immediately preceding control input. His perception of a short runway and the need to constrain the pitch attitude within a very limited range (to avoid a tailstrike) would have motivated the captain to rapidly return the airplane to a stable attitude. He attempted to accomplish this goal with a quick application of large elevator inputs such as throughout the sequence of extreme nose-down and nose-up elevator inputs. However, this succession of elevator inputs and pitch oscillations rendered the landing attempt increasingly unstable.

Another server landing accident involving the airplane skidding off the runway in near-typhoon conditions of rain and wind and flipping upside down – occurred in August 1999 at Hong Kong involving a China Airlines passenger MD-11. Three passengers of the 315 aboard were killed [48].

The Civil Aviation Department of Hong Kong (HKCAD) investigated the accident. “During these approaches, any ability to flare the simulator below 50 ft using the technique recommended in the China Airline Operations Manual and achieve a normal touchdown at low rate of descent proved unsuccessful on the majority of approaches flown; if power was manually applied late in the flare, the rate of descent could be reduced but was still high at touchdown.

In order to compensate for the smaller empennage, the Longitudinal Stability Augmentation System (LSAS) continuously trimmed the stabilizer under computerized controls [16].

Actually, the airplane was performed differently to land. And the HKCAD [48] report noted limitations of the LSAS in providing pitch attitude hold: “LSAS is not provided when the autopilot is engaged. Below 100 ft radio altitude, and transparent to the pilot, LSAS is progressively removed from the pitch control system.”

NTSB [46] “Require, on all MD-11's equipped with the flight control computer-908 software, the retrofit of digital flight data recorder systems with all additional parameters required to precisely identify and differentiate between pilot and longitudinal stability augmentation system (LSAS) elevator control activity, including control column force, inertial reference unit pitch rate, LSAS command signals, elevator positions, and automatic ground spoiler command signals”. However, FAA disagreed and it was “Closed-Unacceptable Action”.

The NTSB [46] urged that the FAA to require the installation of new LSAS software, to allow the airplane less susceptible to over control as a Newark accident recommendations. However, FAA does not believe that basic research based on past accident reports and did not require installation of the software upgrade, as recommended, and this recommendation was closed as “Acceptable Alternate Action.” The alternated condition of software upgrade has been installed on 100 percent of the worldwide MD-11 fleet including the one that crashed at Tokyo. Clearly, alternately upgraded LSAS was not sufficient to fully cure the MD-11’s demanding landing characteristics.

The NTSB [46] also recommended a study assessing “qualitative and quantitative stability and control characteristics” for purposes of implementing “improved certification criteria for transport category airplane designs that will reduce the incidence of landing accidents.” This recommendation was not implemented.

4.2. Causal Factor Analysis using the HFACS Model

4.2.1. Overview of HFACS

As can be seen in Fig. 11 [49-51], HFACS was developed by Dr. Scott Shappell and Dr. Douglas Wiegmann based on Dr. James Reason's "Swiss Cheese" model, and it is used as a tool for causal factor classification and root causal analysis. The purpose of this tool is to break up a potential accident/incident chain by expanding the Unsafe Acts to Organizational Factor and to manage hazards more systemically.

The Australian Transport Safety Bureau [52] analyzed 2,025 accident reports from 1993 to 2003 of airlines in their jurisdiction by using HFACS. The results of the analysis indicated that HFACS can be considered as a predictive tool for SMS. Fig. 12 [52] shows the relationships between Unsafe Acts and higher levels of HFACS. This indicates that an analysis of the Unsafe Supervision of HFACS could predict the "Precondition for Unsafe Acts", as well as "Unsafe Acts" that cause accidents [52].

Recently, even International Air Transportation Association (IATA) introduced the HFACS concept across all Global Audit Programs and has started using it as a fundamental categorization and causal factor analysis tool for Audit Findings. HFACS's High-level causes can be identified and analyzed to predict Unsafe Acts before an accident or incident occurs. Table 6 [49-51] shows a brief description of the causal HFACS categories. Detail guidance for HFACS has attached in Appendix A .

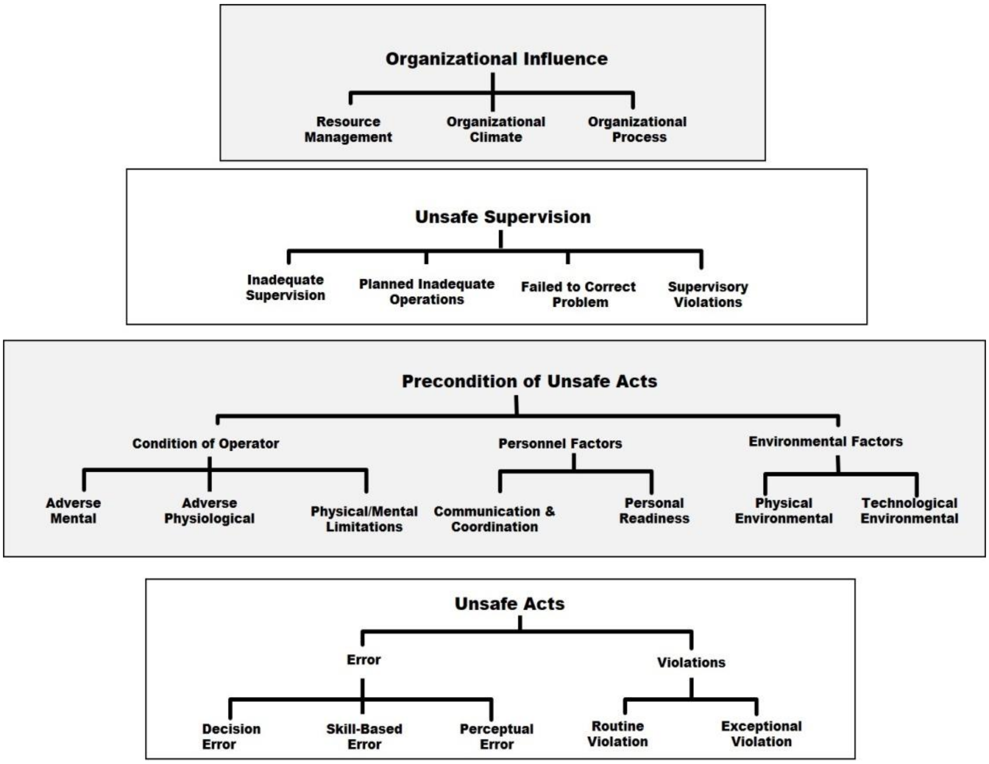


Fig. 11. The HFACS framework [49-51].

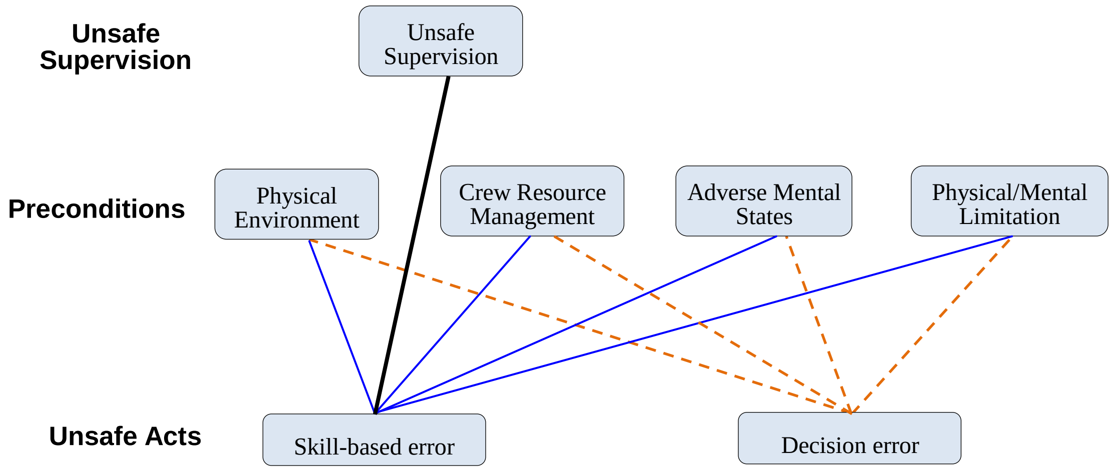


Fig. 12. Relationships between Unsafe Acts and higher levels of HFACS [52]

Table 10. Description of HFACS Causal Categories [49-51]

ORGANIZATIONAL INFLUENCES

Organizational Climate (OC): Prevailing atmosphere/vision within the organization including such things as policies, command structure, and culture.

Operational Process (OP): Formal process by which the vision of an organization is carried out including operations, procedures, and oversight among others.

Resource Management (OM): This category describes how human, monetary, and equipment resources necessary to carry out the vision are managed.

UNSAFE SUPERVISION

Inadequate Supervision (SI): Oversight and management of personnel and resources including training, professional guidance, and operational leadership among other aspects.

Planned Inappropriate Operations (SP): Management and assignment of work including aspects of risk management, crew pairing, operational tempo, etc.

Failed to Correct Known Problems (SF): Those instances when deficiencies among individuals, equipment, training, or other related safety areas are "known" to the supervisor, yet are allowed to continue uncorrected.

Supervisory Violations (SV): The willful disregard for existing rules, regulations, instructions, or standard operating procedures by management during the course of their duties.

PRECONDITIONS FOR UNSAFE ACTS

Environmental Factors

Technological Environment (PET): This category encompasses a variety of issues including the design of equipment and controls, display/interface characteristics, checklist layouts, task factors and automation.

Physical Environment (PEP): The category includes both the operational setting (e.g., weather, altitude, terrain) and the ambient environment, such as heat, vibration, lighting, toxins, etc.

Condition of the Operator

Adverse Mental States (PCM): Acute psychological and/or mental conditions that negatively affect performance such as mental fatigue, pernicious attitudes, and misplaced motivation.

Adverse Physiological States (PCP): Acute medical and/or physiological conditions that preclude safe operations such as illness, intoxication, and the myriad of pharmacological and medical abnormalities known to affect performance.

Physical/Mental Limitations (PCL): Permanent physical/mental disabilities that may adversely impact performance such as poor vision, lack of physical strength, mental aptitude, general knowledge, and a variety of other chronic mental illnesses.

Personnel Factors

Communication, Coordination, & Planning (PPC): Includes a variety of communication, coordination, and teamwork issues that impact performance.

Fitness for Duty (PPR): Off-duty activities required to perform optimally on the job such as adhering to crew rest requirements, alcohol restrictions, and other off-duty mandates.

UNSAFE ACTS

Errors

Decision Errors (AED): These "thinking" errors represent conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. These errors typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation and/or misuse of relevant information.

Skill-based Errors (AES): Highly practiced behavior that occurs with little or no conscious thought. These "doing" errors frequently appear as breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists often appear. Even the manner or technique with which one performs a task is included.

Perceptual Errors (AEP): These errors arise when sensory input is degraded as is often the case when flying at night, in poor weather, or in otherwise visually impoverished environments. Faced with acting on imperfect or incomplete information, aircrew run the risk of misjudging distances, altitude, and decent rates, as well as responding incorrectly to a variety of visual/vestibular illusions.

***Violations* (V)**

Routine Violations (AVR): Often referred to as "bending the rules" this type of violation tends to be habitual by nature and is often enabled by a system of supervision and management that tolerates such departures from the rules.

Exceptional Violations (AVE): Isolated departures from authority, neither typical of the individual nor condoned by management.

Fig. 13 shows general overview of causal factor by HFACS model for MD-11 severe hard/bounced and tail strike landings accident/incidents. These unique design characteristics are "Precondition of Unsafe Acts" for severe hard/bounced and tail strike landings. And its Precondition was continues existed due to "Unsafe Supervision" that allows a lack of oversight to strength the procedures and training to reflecting these design characteristics. Also, the factors of failure to improve and/or correct known hazard were considered as an Unsafe Supervision. Detail HFACS analysis will be follow next chapter 4.2.2.

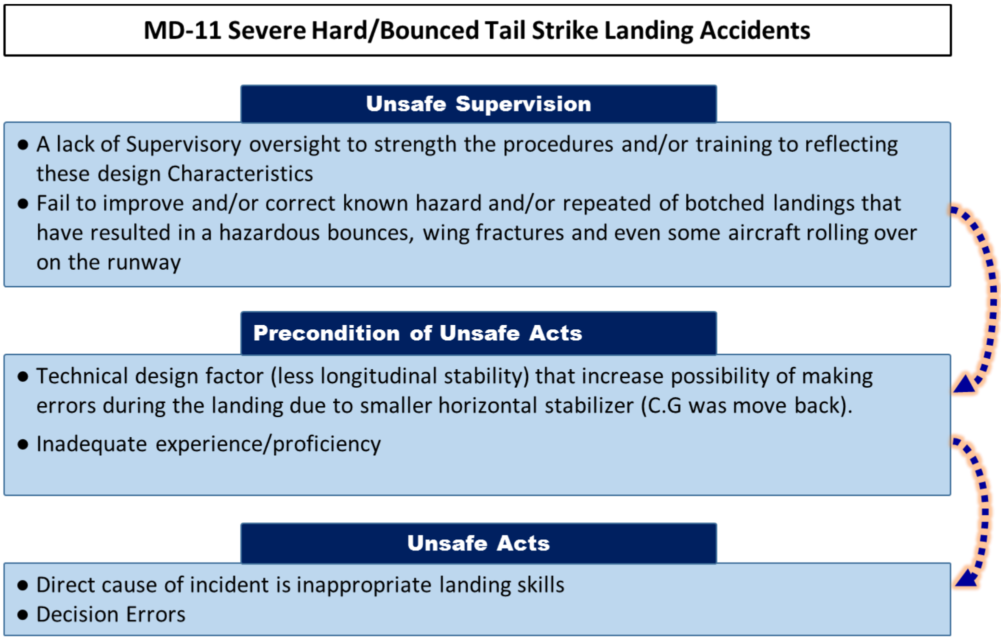


Fig. 13. MD-11 Root Causal Analysis.

4.2.2. Results

We have evaluated 19 cases of severe hard/bounced and tail strike landings accidents/incidents of MD-11 aircrafts in this study. From these 19 accident/incidents, a total of 101 causal factors were identified and used for analysis. As can be seen on Table 11, causal factors are involved throughout 4 HFACS levels. Within the category of Unsafe Acts of Operators, the most frequently cited form of error was Decision Errors. With regard to the Preconditions for Unsafe Acts, the majority of causal factors have involved the Physical Environment and Technical Environment. In the level of Unsafe Supervision, Inadequate Supervision and Failed to correct known Problem were identified. Typically, fewer causal factors were identified at the Organizational Influence levels. However, at this time, the number of the Organizational Process and Oversight identified is similar to the number of Unsafe Supervision and Preconditions for Unsafe Acts. It means organizational levels of corrective actions are needed in order to correct MD-11's concerned issues fundamentally.

Table 11. MD-11 Frequency of Cases associated with Causal Code Categories.

HFACS category	n
Organizational Influence	**20**
Resource Management	
Budget Resource	1
Organizational Process	
Procedure	8
Oversight	11
Unsafe Supervision	**21**
Inadequate Supervision	
Inadequate Supervision of Training	10
Inadequate Supervision of Guidance/ Oversight	1
Failed to correct known Problem	
Failed to correct known risky problems	10
Preconditions for Unsafe Acts	**24**
Condition of Operator	
Physical/Mental Limitation	4
Personnel Factors	
Communication and Coordination	3
Environmental Factors	
Physical Environment	2
Technological Environment	15
Unsafe Acts	**36**
Decision Error	35
Skill-Based Error	1

As can be seen in Fig. 14, there were no significant changes on Decision Errors from 1993 to 2013. The lines were essentially flat, showing that any interventions aimed at reducing specific types of human error prior to, or during this time period did not appear to have any long term influences. Recently, even errors are increased more.

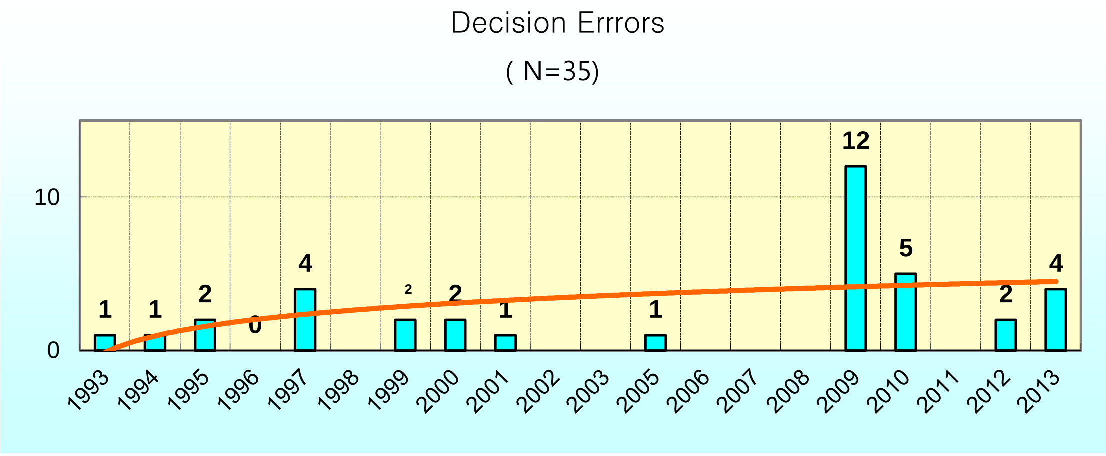


Fig. 14. MD-11 Decision Errors from 1993 to 2013.

Decision Error is the most common type of error associated with aircraft operations. It assumes that each individual has the knowledge of the procedure. However, an operator may perform a task incorrectly simply because they do not know the correct procedure either due to lack of training or retention of information. Regardless, these types of errors suggest that specific training or new cockpit system aids, and cues are necessary to assist MD-11 pilots to make better decision and reactions.

As can be seen Fig. 14, 24 factors were observed in the level of Precondition of Unsafe Acts (Physical/Mental Limitation, Communication and Coordination, Physical Environment, Technological Environment). Among these, Technological Environment was the most frequently identified precondition. MD-11 has design characteristics such as light control force and nose up during landing. It was expected that this unique design characteristics have influence to high possibility of severe hard/bounced and tail strike landings accident/incidents.

Unsafe Supervision was identified in 21 factors of cases analyzed. The majority of causal factors at this level fell into the "Failed to correct known risky problems" and "Inadequate design of training program."

Organizational Influence was identified in 20 factors. 19 factors among these fell into the "Inadequate training/procedures/guidance" and "Inadequate training oversight." Three years after the Newark accident which had occurred in 1997, FAA has issued Advisory Circular 120-71, "Standard Operating Procedures for Flight Deck Crew Members" and Bulletins to discuss stabilized approaches and reduction of approach and landing accidents. However, these were generic guidance, and not sufficient or effective for MD-11's particular safety problems.

4.3. Risk Assessment using by Transport Airplane Risk Assessment Methodology (TRARM)

4.3.1. Overview of TRARM

TARAM was developed for FAA aerospace safety engineers to calculate the specific levels of risk associated with identifiable design flaws in transport airplanes. Detailed instructions and guidance are given in terms of using the risk analysis calculations when making safety decisions. The life-risk data in Fig. 15 [53] indicates the difference between individual risk, which is calculated according to the guidance provided in the handbook, and risk is associated with various aspects of daily life. According to TARAM [53], risk associated with a single continued operational safety issue should not result in individual risk above 10-7/hr. The level of individual risk may require urgent action, and it was concluded that urgent action is required halfway between the 10^{-5}/hr and 10^{-7}/hr safety level [53].

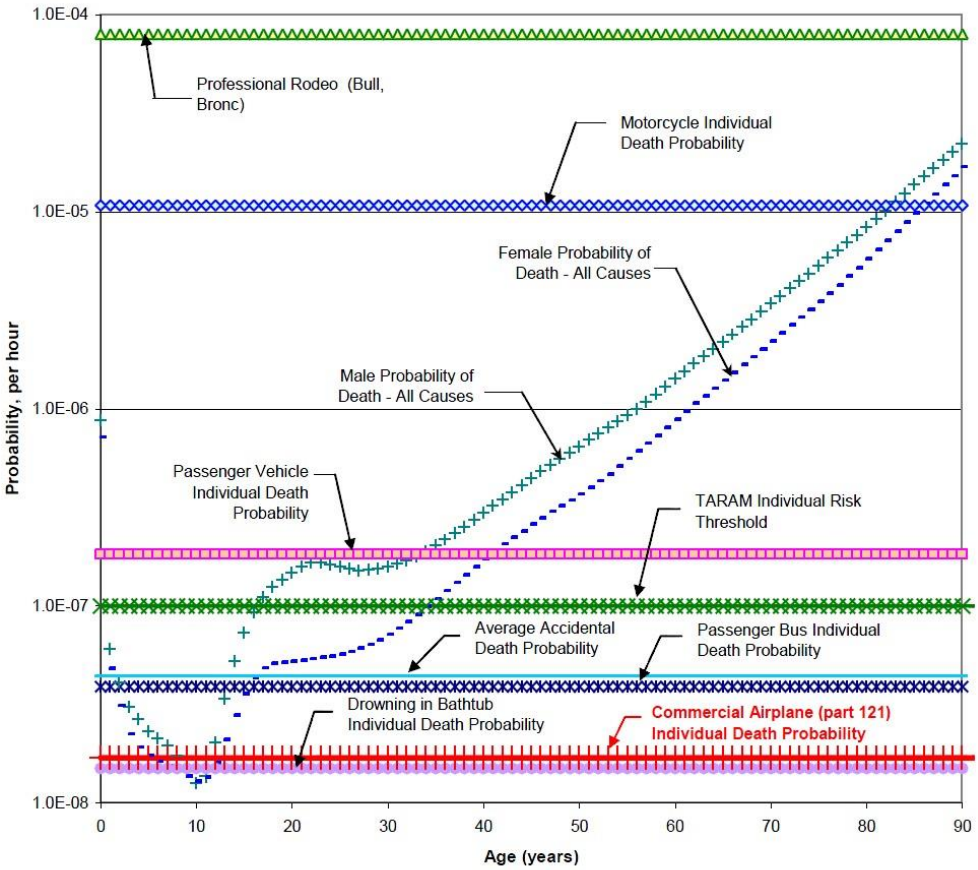


Fig. 15. Life Risk.

The following is the key equations to calculate risks by TRARM [53].

Fleet exposure: U x T x Σ (1)

Predicted number of Occurrences: U x T x Σ x F (2)

where U is the utilization, the average flight hours, T is the time, and Σ is the Number of Airplanes.

Severity: $S = IR$ (3)

where IR is the injury ratio that indicates the average single-event probability that those exposed to a particularly dangerous event will suffer a fatal injury.

Fleet Risk: $R = (U \times T \times \Sigma \times F) \times CP \times S$ (4)

Individual risk: $R = F \times CP \times S$ (5)

where CP is the probability that the particular condition under study will result in a dangerous event with a known severity.

The frequency of the occurrence (F) is defined as the expected rate at which the condition that is under study will occur within the affected fleet. These can be calculated as the number of occurrences divided by total fleet flight hours.

4.3.2 Results

"Individual Risk" is defined as the probability of a fatal injury per flight hour, and the "Fleet Risk" is defined as a constant failure rate in the FAA TARAM handbook [53]. According to TARAM, cases where sufficient practical data is not available involve the accepted engineering practices of determining the "best estimate" of the actual quantitative values needed to determine risk.

The calculation of F for the individual risk and fleet risk for MD-11 severe hard/bounced and tail strike landings is as follows.

$F = 19 / 2{,}490{,}000$ hrs. $\cong 7.6 \times 10^{-6}$/hr.

where 2,490,000 total fleet flight hours and 19 occurrences took place for the MD-11 severe hard/bounced and tail strike landings.

CP = 0.333

IR= 0.5

Individual Risk = (6×10^{-6}/hr.) x 0.333 x 0.5

, where 0.333 (CP) and 0.5 (IR) was estimated.

Individual Risk $\cong 4 \times 10^{-7}$/hr.

Fleet Risk = (1,300,000* x 6×10^{-6}/hr.) x 0.333 x 0.5 $\cong$ 1.3

*To determine the fleet exposure, instead of using Equation (1), the estimated flight hours were compared to the actual fleet flight hours of aircraft of a similar size and with the operating time periods.

The TARAM guideline for normally accepted individual risk values is below 1×10^{-7}/hr. The results of the individual risk values were 4×10^{-7}/hr for MD-11 and it was above an acceptable level. And the TARAM guidelines for the normally accepted fleet risk are below 0.02. This was also, greater than the acceptable levels, which MD-11was 1.3.

Chapter 5. Discussion

5.1. MD-11 Safety Records

200 MD-11s have been manufactured over the last ten years since the first delivery on November 1990. In the case of the A330, which was first delivered in 1993 at the similar time period as the MD-11, the accumulated number of orders is 1174 as of March 2015. The production of MD-11 came to a halt in 2000 due to the failure to receive further orders. Since it was no longer desired in passenger plane market, many air carriers converted their MD-11s to cargo aircrafts.

The MD-11 had suffered 19 severe hard/bounced and tail strike landings accidents/incidents between 1993 and 2013, which is the highest rate of such dangerous touchdowns based on the number of flights among Western-built jet models. Fig. 16 [3, 54] shows the Accident Rates by Airplane Type, and normally, each new generation of airliner crashes less frequently than past models. In terms of aircraft losses per million departures, the MD-11 has a record that is more than 10 times worse than that of the Boeing 747-400, which was introduced in 1989 with similar technology. That is also 15 times worse than that of some older 757 and 767 models.

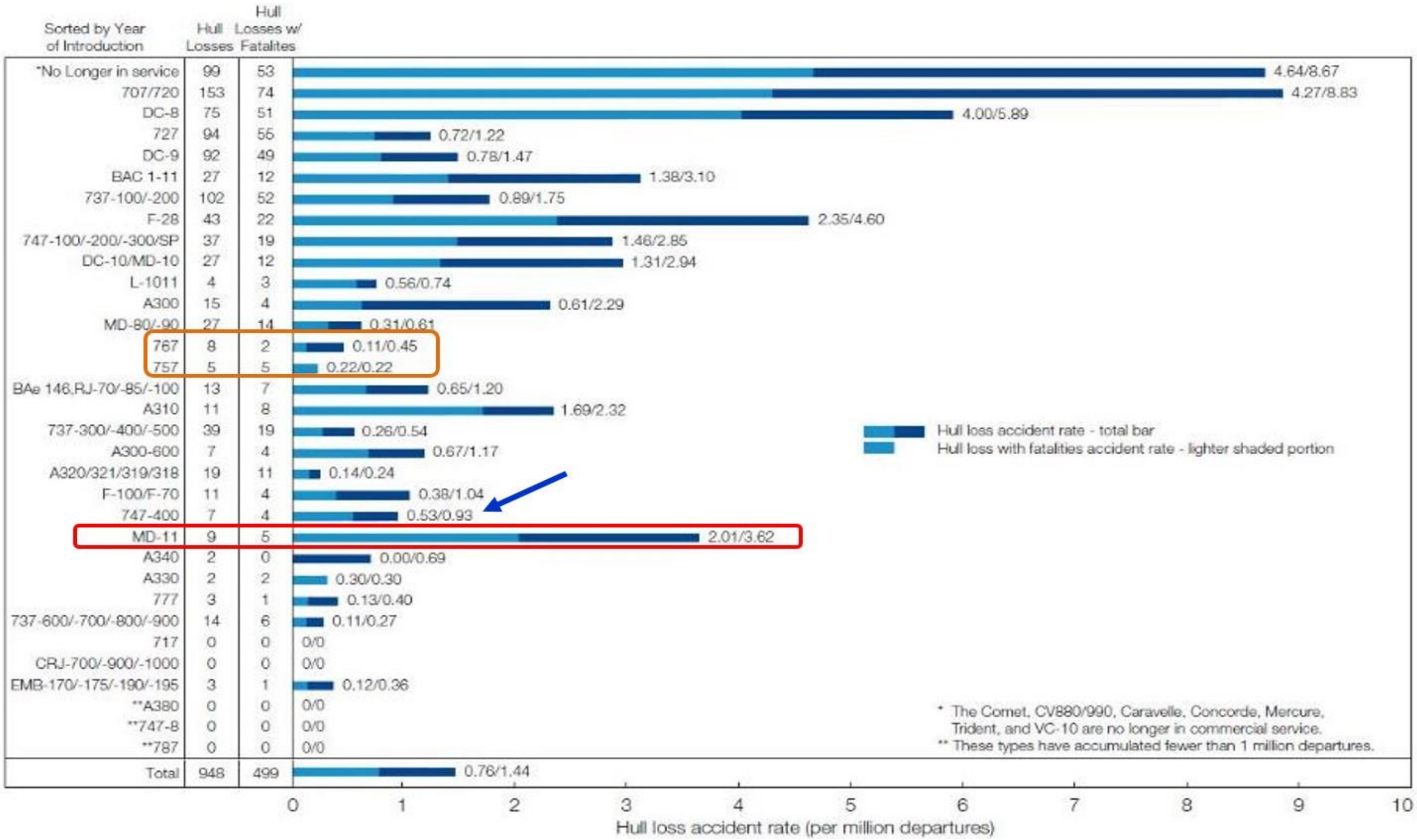


Fig. 16. Accident Rate by Aircraft Types [3, 54].

5.2. Safety Risk Management

Aircraft manufacturing industries differ from other aviation industry businesses. They must deal with product lifecycles, such as requirements, design, testing and certification, production, support, and product retirement. In other words, they have to manage the safety of their fielded product (SMS), as well as the processes which create the product (QMS).

So, in SRM's point of view, how MD-11 aircrafts' severe hard/bounced and tail strike landings accidents could be managed and prevented /mitigated? It was discussed what SMS's roles can be contribute to this in this chapter.

5.2.1. Change Management

The concept of change management is relatively new to aviation industry. In fact, many organizations will rarely take the time to plan, organize and document change within the organization. A common philosophy is to rely on dedicated employees to spend the extra effort required to implement the change by processing their way through the project to make up for the inadequate planning up front. ICAO states [10-11]. 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 arrangement to ensure safety performance.

Aircraft accidents have been reduced through incremental changes in cockpit automation and maintenance practices, training programs, etc. Although many aviation companies consider themselves adaptable to economic or competitive changes, most of these change processes have not been formally documented throughout the organizations.

Every company is changing. The important factor is, “Is the organization guiding this change, encouraging improvement and investing in employee skills to accelerate change?” MD-11's center of gravity was designed to be located much further after than that of other commercial aircraft to improve fuel efficiency, and smaller horizontal stabilizer was designed to compensate heavy tail down force. This new design concept was introduced to the commercial aircraft first time. According to the SMS concept, potential hazards surface whenever changes are introduced, and assessment, monitoring, and risk mitigation actions are therefore required. If an effective SMS (Change Management) was systemically implemented throughout the organization, these failures could be predicated, prevented and/or mitigated more efficient way. The hard landing hazard of the MD-11 existed from the beginning of the aircraft development process. However, both manufacturers and the authorities failed to assess possible new or existing hazards systemically and effectively.

5.2.2. Organizational and Human Factors Approaches

The landing environment brings many challenges for the pilot. Pilots make control inputs based on their perceptions and experiences. When approaching for landing, the pilot must align the aircraft with the runway, and then manage the descent rate to perform a smooth touchdown. This also must occur within the appropriate touchdown zone, which will enable the aircraft to have enough runway remaining to safely stop. Once main landing gears make contact to the ground, the pilot will lower the nose of the aircraft to the ground, and apply reverse thrust and brakes to stop the aircraft. This is extremely dynamic environment, which requires a repetitive cycle of perception, action, and feedback from the environment with immediate corrections to any unexpected situations.

The forward and aft limit of the CG range of the aircraft is certified by the manufacturer. The pilot should realize that if the CG is displaced too far forward on the longitudinal axis, a nose-heavy condition will result. Conversely, if the CG is displaced too far after on the longitudinal axis, a tail heavy condition results. It is possible that the pilot could not control the aircraft if the CG location produced an unstable condition.

They may face with a position where their perceptions do not match the actual aircraft dynamics and operational environments. According to HFACS's analysis, Technological Environment was the most frequently identified precondition for MD-11's Unsafe Acts. MD-11's new design characteristics were added on extremely dynamic landing environment, and significantly influenced pilot's unsafe acts.

The area involving safety problem has broad meaning than that of reliability problem. For system safety prospective, under the unexpected conditions, more complicated outcomes were occurred based on organizational and human factor that interacts with those systems. It was required to consider not only reliability of component but also system design, dynamic operational environment, human factor, and organizational factors. MD-11's potential risk for severe hard/bounced and tail strike landings could be controlled and/or mitigated if it was systemically handled based on factors of interactions of airplane and pilot responses, and the effects of adverse environmental conditions.

Based on the accident and incident records, the NTSB [55] is concerned that certain complex system interactions, pilot input characteristics, and other factors, such as CG position and atmospheric conditions, may occasionally combine during the landing phase in undesirable ways that were not identified during the original certification of transport airplanes.

5.2.3. Identify and Mitigate Root Cause of Accidents

HFACS is one of the useful SMS tools to identify and mitigate the true causes of hazards, incidents and accidents. We have verified that the root causes of MD-11 accidents/incidents could be classified into HFACS's higher level, which refer to the management of the design and certification process. According to research in Austria [52], accidents/incidents could be predicted and prevented if HFACS's higher level, such as Unsafe Supervision and Organizational Influence, were closely monitored, identified, and effectively managed.

Through an analysis using the FAA TARAM model, we have examined that the risk level of the severe hard/bounced and tail strike landings of MD-

11 aircrafts is still at the unacceptable level. This indicated exactly how it is important to manage safety risk from the beginning of the aircraft design process, and to systematically link this safety risk after the aircraft is entered into service, since this can have a significant influence on the safe operation and life cycle of the aircraft.

QMS and reliability program were not enough for managing safety risk throughout aircraft life cycle. SMS is an effective tool to identify, assess, and mitigate safety risks more systemically, by using proactive and predictive methods of safety risk management rather than reactive.

It is difficult to understand that certain organizational decisions could impact the safety of a product. Even after the FAA's corrective actions in 2000, MD-11 crews had continued to have difficulty in judging the appropriate operations to avoid or recover from hard landings, and 13 more accident/incidents were occurred after that. It's because the FAA's generic guidance for MD-11's particular safety problem was neither sufficient nor effective. Through the analysis of Decision Errors by HFACS, it was verified that any interventions aimed at reducing unsafe acts prior to, or during this time period did not appear to have any long term impact.

If true root causes of MD-11 landing accidents were identified, and organizational levels of corrective actions were taken appropriately, the additional 13 more MD-11 accidents could be prevented and/or reduced after the year of 2000.

5.2.4. Integrated SRM and SA Functions

Every commercial aviation industry must adopt the concept of continual improvement in order to survive, compete in the global market effectively. Continual improvement is a process that enables proactive risk management through process assessment and improvement of products, services or processes.

Integrated SRM and SA functions can be tools for continual improvement. After the system is designed or redesigned using the risk assessment process, the new or revised system, procedure, or any other should be closely monitored by continuously using the SA process. The SA interacts with SRM to ensure that risk controls are practically in effect and that they continue to obtain their intended level of acceptable risk through continuous measurement and monitoring of the performance of the system. The MD-11 aircrafts are still suffering severe hard/bounced and tail strike landings to date. With effective SMS's integrated SRM and SA, potential risk of MD-11 aircrafts' severe hard/bounced and tail strike landings could be managed and prevented /mitigated.

This tool can be applicable in situations below:

- When developing a new or improving the design of a process, product or service
- When planning data collection in order to verify and prioritize problems or root causes
- When implementing any change
- When starting a new improvement project

5.3. Proposals for Effective SMS Implementation in Aircraft Manufacturing Industry

FAA has played critical roles for aircraft manufacturing industries in the international aviation safety certification process. Therefore, the SMS regulations established by the FAA have a high possibility of being adopted as the international SMS regulation model in the future.

Specially, through the SMS pilot project, FAA has established the related guidance materials for manufacturing industries to effectively implement SMS implementation. FAA has approached systemically to establish practical SMS regulation that could positively be adopted by manufacturing industry and effectively oversight these industries.

The following are proposals for aircraft manufacturing industries to effectively implement SMS based on recent legislation changes. Especially, FAA's SMS Part 21 rulemaking progress and their oversight changes were considered for manufacturing industries to efficiently prepare and practically implement SMS.

5.3.1. Integrated Approach to Safety Management

Integrated approach to safety management enables managers to recognise and take into account all significant influences on their organisation. It is such as a creating a single management system with integrated safety objectives emphasizing safety management as a fundamental business process to be considered in the same manner as other aspects of business management [10-11].

Integration requires a clear picture of all aspects of the organisation and knowledge of how they affect each other. It is seen as the best option to minimise risks and maximise resources [33]. Through the integration of business management system within industries, we could reduce in duplication of systems and processes. The structure of SMS provides organizations greater insight into their operational environment, generating process efficiencies and cost savings.

While some of aviation manufacturing industries are well organized with QMS, still do not see values of SMS. In case of aviation industry organization which utilizes QMS alone, they may also effectively adopt a safety risk concept to their QMS procedure. Through the mutual reinforcement of SMS, QMS can now satisfy requirements and safety basis of customers, companies, or regulatory. Therefore, it was reviewed and proposed SMS/QMS integrated process focusing safety risk management.

There are obvious advantages of harmonizing the framework of SMS and QMS. While safety assurance focuses on risk management for achieving safety goals, quality assurance constantly focuses on product suitability and customer satisfaction. These two management systems can mutually reinforce each other and allow efficient safety management.

In this paper, the process have been reviewed which QMS and SMS could relate or integrate each other. Also, the process how to be integrated for more efficient approach to safety risk management is identified.

In general, in the operational environment where the existing QMS and SMS are separately utilized, QMS and safety risk management can be related or integrated, allowing the efficiency and the following advantages [10-11].

- Reduction in duplicating function, and cost reduction
- Efficient risk management, and increase in profit
- Balance of potentially conflicting objectives
- Elimination of potentially conflicting responsibilities and relations

Fig. 17 shows related and integrated utilization of SMS/QMS for efficient and constant risk management.

① Conduct risk analysis for audit finding (Non-conformity)

- Providing data for integrated risk management process on audit finding as well as safety reports and investigation.

② Establishment of risk-based safety management

- Determining risk priority and area through collection of and integrated analysis on safety data.
- This allows determining to areas of priority on audit/inspection and concentrated management on vulnerability of safety through risk analysis base.

③ Integration of Safety Audit and Quality Audit

- This allow efficient safety risk management by focusing on change in management of safety assurance, reinforcing checklist based quality audit function to improve hazard identification function in on-site operational environment.
- SMS training on existing quality auditor and reinforcement on ability to see beyond checklists which is performance based approach.

④ Constant monitoring and improvement

- Constant monitoring on safety and system that allows efficient risk management, through the establishment of the process in which SMS and QMS are mutually reinforced and connected.
- In case of constant monitoring for dynamic aviation industry, it is required for management level to make safety decisions based on constant analysis on safety data for balanced operation on safety/quality assurance and investment on service.

⑤ Integrated management review which duplicates with SMS/QMS

- Reduction in duplicated function of SMS and QMS Management Review representative in general organization
- Expectation of increase in work efficiency and cost savings.

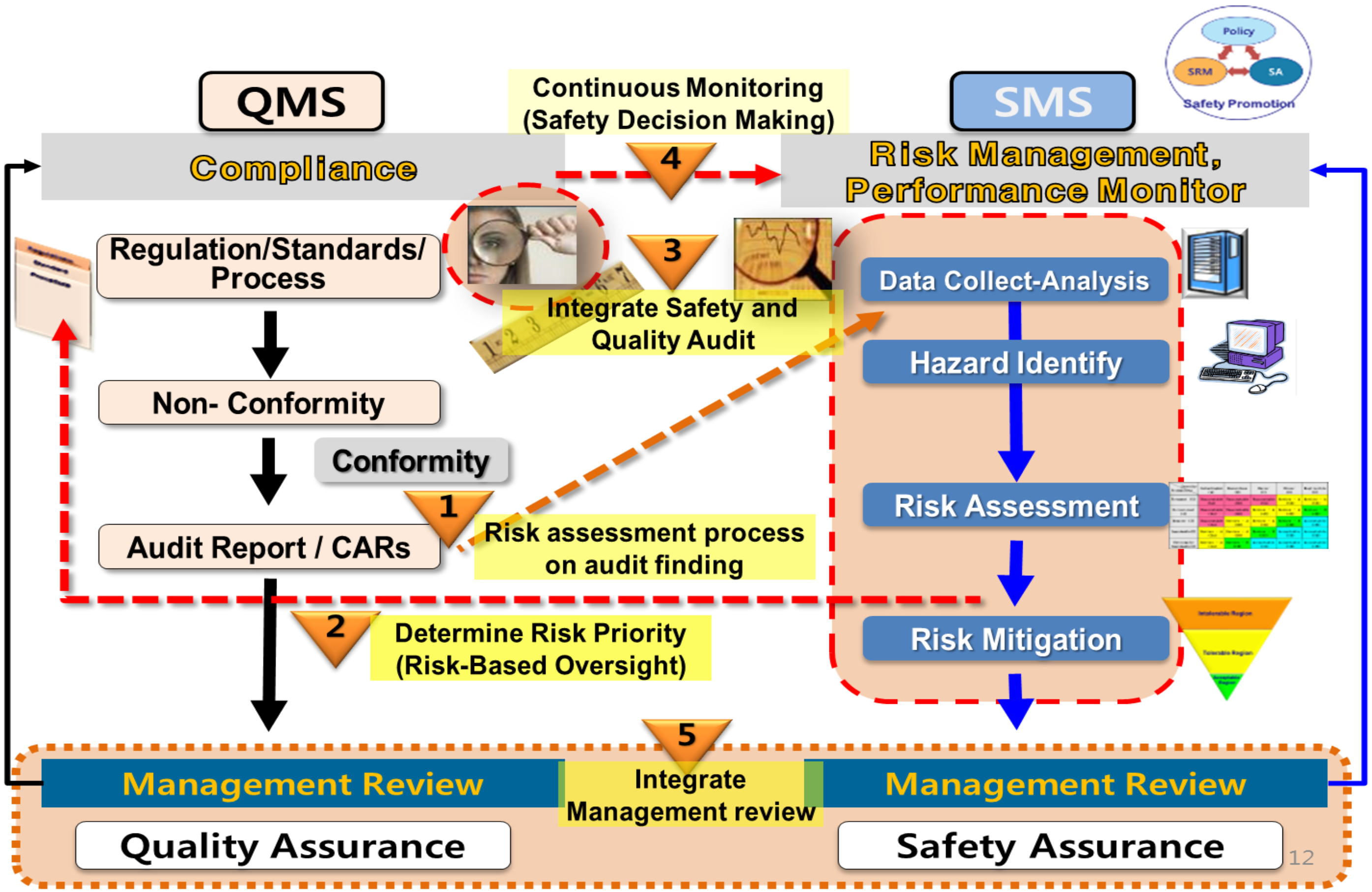


Fig. 17. Integrated Approach to SMS with QMS

We may think SMS and QMS are similar to each other, but there are differences in each category. The most important difference between SMS and QMS can be divided into finding risks and finding defects. QMS focuses on customer/achievement and production/service, and SMS is more focused on constant management on factors that affect internal safety and risks.

SMS is the more systemic and organizational management system to maintain the risk factors that can cause loss of human lives or properties to be at or under the level of acceptance, through identification of constant hazards and risk management. In contrast, QMS is referred to as all operational activities in which the organizational activities, plan, or responsibility are for assuring satisfaction of requirements of customers and regulatory organizations. Therefore, mutual reinforcement and integrated utilization of SMS and QMS is the significant factor for efficient risk management and safe operation

Chances for improvement can be found in data/information, and collection and systemic analysis/utilization of data is the prerequisite and the most important function for integrated utilization of SMS/QMS. Also, it is never too much to emphasize that the quality and maintenance of data is the most important factors to make decisions on safety, such as redistribution of resources for reducing risk.

Through mutual reinforcement and integrated utilization of SMS/QMS associated with collection of and integrated analysis on various safety data, it is possible to predict the vulnerable areas where risk management is required, and determine the risk priority and priority on areas where audit/inspection is needed. Through this, it is possible to predetermine the vulnerable areas and efficiently manage risks.

Integrated utilization of safety audit and quality audit is the terms for high quality safety risk management. As introduction of SMS concept into quality audit which is conducted by checklist regarding regulations, standards, and procedural compliance, inspection methods, such as safety performance monitoring is required additionally. To successfully integrate audit functions, professional SMS trainings for the QMS auditors are important factors.

The auditor’s role will be emphasized into the inspection method that makes possible to detect hazard in safety, monitoring, or operations along with inspection method based on checklists. If QMS is embodied with mutual relationship for safety risk analysis, that SMS can be expected to function significantly as even more strong safety barrier of aviation industry.

5.3.2. Phased SMS Implementation

An SMS cannot be built overnight. It is unrealistic to expect an organization to have an effective SMS from its first day of implementation. SMS implementation takes more time and effort as the organization becomes bigger. Thus, it is highly recommended to develop a phased SMS implementation. It could be beneficial for both manufacturing industries and respective authorities to effectively implement SMS and determine their effectiveness as each phase is completed. Authority is highly recommended define the level of phased SMS implementation depending on the type of organization, type of certificate held, the size and complexity of the organization, the type of operation (e.g., air operator's certificate, manufacturer) [43].

Both Industries and respective authorities will have manageable series of steps to follow with clearly defined expectations for each phase; for continuous improvement through “lessons learned”; and for an effective implementation of SMS. In this way, industries could have practical and/or realistic SMS implementation to improve their actual their safety of operations.

5.3.3. Modify based on Industry’s Environment

One SMS and oversight method to fit for all the aircraft manufacturing industries is not easy to develop. Even it is not a practical way to approach for effective SMS implementation.

Due to the nature of the aircraft manufacturing industry, there are many different types of companies depending on size and complexity of the operations to be covered, volume of data available, the size of the employee workforce, and the resources needed to manage the organization [22-24, 31].

During the rulemaking of part 121 SMS, FAA has broken it down into a small carrier as carriers operating fewer than 10 airplanes; medium carriers as those with fewer than 48 airplanes; and large carriers are those with more than 48 airplanes. For example, SMS requires employee reporting system, and for the medium and large carriers which have many more employees and need reporting system such as a software and/or electrical database system. However, small carriers have much less employees and do not require “system” and/or “electrical database”.

FAA [22-24, 31] has accepted as means of alternative way of employee reporting system requirement. For these small companies do not need to be highly sophisticated. The employees might report a hazard either orally or in a note or via email to their supervisor. Collection tools could be a suggestion box, voice mail “hotline,” etc.

Most regulation defines “what” must be accomplished, not “how” it must be done. One of the best ways to get the effective and practical SMS implementation could be developing SMS to match with industries environment.

There should be various guidance materials that align with the SMS requirements. These could assist manufacturing industries to understand acceptable means as well as implementing and maintaining of SMS.

It could be very critical factors that industries are closely communicating and coordinating with their respective regulatory for developing practical and effective SMS procedures to match with their environment. Without this important process, their SMS will be less effective and/or less realistic implementation. Another words, it could result “cosmetic implementation” without getting practical benefits from SMS implementation.

5.3.4. Coordination for Global Market

One of the natures of global aircraft market is that more than two companies and/or two different countries are working together. Therefore, global partnerships between industries as well as authorities are necessary to establish effective SMS for entering global aircraft market.

As we have understood that FAA's SMS rule can be expected as an international model in aircraft manufacturing industries. FAA will mandate SMS requirements in the aircraft manufacturing by 2017 [5]. In addition, SMS will be applied in the BASA program. U.S industries will have 3 years grace period for their full SMS implementation. During that time of period other countries' authorities will require establishment of SMS regulation for their aircraft manufacturing industries to meet ICAO SMS requirements.

According to BASA, this will be necessary to export their aircrafts and products to the U.S and/or global aircraft markets. It is highly recommended for both aircraft manufacturing industry and designee organization to participate in the authority's SMS rulemaking process and provide actual operational feedback depending on their organizational environments. This could make for authority SMS regulation more effective.

Also, an authority maintains and/or going to export their industries aircrafts and products requires communicate with other countries to make sure their SMS rules are acceptable globally and effective. It could be better to participate in SM ICG or closely monitoring their corporate activities. SM ICG was explained in the Chapter 3, and the purpose of SM ICG will be to harmonize SMS efforts, collaborate on topics of common interest, share lessons learned, and ensure the progression of SMS in a similar direction.

Aviation authorities will have benefits from collaboration and sharing of lessons learned and best practices. They could avoid duplication of efforts, make it better to share information, and assist in developing robust and affordable safety management systems.

Through the all these coordination, aircraft manufacturing industries could develop effective SMS that is acceptable globally and making easy to.

5.4. Limitations

Some of the aircraft manufacturers have well-organized QMS and hardly see value in SMS. SMS is a somewhat newer approach for most these industries, and it is necessary to provide detailed guidance to successfully implement SMS in their aircraft development processes. SMS cannot be built overnight, and it takes time for the aircraft manufacturing industry to follow step by step implementation within their organization to obtain the real and effective value of SMS.

To obtain real value from SMS, SMS training and systems require sufficient oversight of SMS activities.

It is challenging to utilize existing management systems by integrating SMS while avoiding duplication of systems and processes.

Finally, gathering safety data from the beginning of aircraft development and throughout the entire life cycle of the aircraft could be challenging. These data could be more effectively obtained by establishing a positive reporting system under non-punitive reporting environments. Many countries still face challenges to establish non-punitive, positive reporting cultures.

Chapter 6. Conclusion

In the aviation industry, complex and advanced systems are constantly being developed and introduced. Although the reliability of aircraft has been systematically improved as such advanced technology is further developed, the organizational and human factors that interact with those systems are the fundamental causes of the accidents [1, 2].

In cases where aircraft accidents and incidents are exposed to public, the cost is tremendously high. As we have seen through the case study of MD-11, successful aircraft development in the global market depends on identifying safety risks and mitigating these risks through continuous and systematic safety management By adopting and implementing SMS required by ICAO in aircraft manufacturing industry, managing safety risk and operational safety will be improved.

Aspects from safety management point of view the most aircraft manufacturing industries are faced with 1) more complex and advanced systems are newly and constantly introduced, 2) accidents that might be increase as increasing air traffic volume, 3) working environments more than two companies and/or two different countries with joint and/or outsourcing, and 4) management dilemma between “Protection” and “Production” which requires appropriate decision to make balance. SMS is a very effective safety risk management solution for the current complex aviation industry environments.

Most of the aircraft manufacturing industries already had QMS and reliability program as part of their aircraft certification process. Identification of hazards associated with organizational factors, including human performance within an organization, is a paradigm shift to systemic safety management. SMS is intended to identify safety hazards and evaluate related risks, and effectively manage risks. In contrast, QMS is concentrated on compliance in regulations, requirements for satisfying customers' expectations, and requirements on the contracts. The area involving safety problem has broader meaning than that of the reliability problem. For system safety prospective, it is necessary to consider not only reliability of component, but also system design, dynamic operational environment, human factors, and organizational factors.

This paper conducted a root cause analysis and risk assessment for MD-11 aircrafts' severe hard/bounced and tail strike landings accidents/incidents, in order to verify how it is important to manage safety risk from the beginning of the aircraft development stage. We have found that the risk of the MD-11 is still at the unacceptable level. After an aircraft has entered into service, it is important to establish a link within the system for the risk to be continually monitored, assessed, mitigated, and controlled in actual operating environment. This safety feature of an aircraft can be a strong source of competitiveness in the global aircraft market [56]. Ultimately, these activities reduce the costs for direct/indirect correction and/or redesign due to system failures.

The FAA [22-24, 31] plan to adopt SMS in the Bilateral Aviation Safety

Agreement (BASA) program after the SMS rulemaking will be completed in FAA Part 21. A country signs the BASA agreement with U.S to export their aircraft and/or products in the global market, will be required to prepare and establish SMS in order to fulfill the ICAO and FAA requirements.

From the point of effective safety risk management prospective, this paper has proposed integration between existing management system in most cases, QMS with SMS. There are obvious advantages of harmonizing the framework of QMS and SMS. In general, in the organizational environment where the existing QMS and safety are separately utilized, QMS and safety risk management can be related or integrated. This could be efficient and have advantages in reduction in duplicating function, cost saving, efficient risk management, elimination of potentially conflicting responsibilities, and etc.

A SMS cannot be built overnight, and it takes time for aircraft manufacturing industry to follow step by step (phased approach) in order to implement. For developing affordable SMS, it is required to adopt SMS that practically match with their organizational environments. Lastly, it is highly recommended to closely coordination with respective authority for developing effective SMS that would be acceptable globally.

In addition to the aircraft manufacturing industry, SMS can also be adopted in a wide range of other areas, such as private aerospace, unmanned aircraft, small helicopter, in order to effectively manage safety risk and prevent accidents.

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Appendix A. Guidance for HFACS

Human Factors Analysis and Classification System (HFACS) was developed by Dr. Scott Shappell and Dr. Douglas Wiegmann based on Dr. James Reason's "Swiss Cheese" model [10]. The purpose of this tool is to break up a potential accident/incident chain by extending unsafe acts to organizational factor and managing hazard more systemically.

Reason's model describes four levels of failure. These includes: 1) Unsafe Acts, 2) Preconditions for Unsafe acts, 3) Unsafe Supervision, and 4) Organizational Influences. However, while Reason's model is useful in describing the cascade of events leading up to a particular accident, it did not set out to identify all the "holes" in the cheese, i.e., those active and latent failures at each level of failure. A limitation of Reason's model is that it fails to identify the exact nature of "holes" in the cheese.

1. Unsafe Acts

Unsafe acts are described as "active" failures or actions committed by the employee that result in human error or an unsafe situation. As can be seen Fig. A.1, these are categorized into two groups: errors and violations. These can be a consequence of organizational influences, supervisory issues, and/or preconditions.

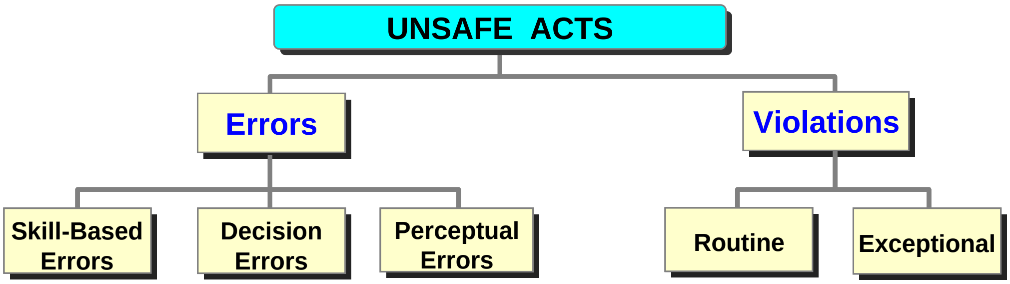

Fig. A. 1. HFACS-Unsafe Acts

1.1. Errors

Errors represent the mental or physical activities of an employee who fails to achieve his/her intended outcome. Errors are not intentional.

Skill-Based Errors

- Can be mistakes that are associated with a lack of general skill, training, or an employee's capability.
- Can also be viewed as "stick-and-rudder" and other basic skills (or routine activities) that occur without significant conscious thought (e.g., driving, typing).
- Tend to occur when actions are vulnerable to failures of attention, memory, and/or technique (such as the failure to keep your eyes on the road, task fixation, the inadvertent activation of controls, and the mis-ordering of steps in a procedure).

- May occur in the employee’s execution of a routine, highly practiced task relating to procedure, training or proficiency.
- Skill-based Errors are unintended behaviors.

Decision Errors

- Represents intentional behavior that precedes as planned, yet the plan itself proves inadequate or inappropriate for the situation or desired goal.
- Referred to as “honest mistakes”- “heart’s is in the right place,” but the individual either did not have the appropriate knowledge or just simply chose poorly.
- Procedural decision errors (or rule-based mistakes) – when decisions are routine, errors can, and often do, occur when a situation is either not recognized or is misdiagnosed (e.g., a situation that requires quick decisions as in the case of an emergency or when the boss “wants it right now!”).

Perceptual Errors

- Perceptual Errors occur when sensory input is degraded or “unusual,” or when operators simply misjudge the height or distance between themselves and other objects and a decision is made based on faulty information.

- Factors in an incident when the misperception of an object, threat, or environment results in or contributes to an unsafe situation.

1.2. Violations

Violations represent a willful disregard for the rules and regulations that govern safe completion of a task. Violations are intentional. The key word here is “willful.” In other words, the individual must know the rules and have intentionally disregarded them.

From a safety perspective (not legal perspective), it means ignorance of the rules and regulations changes an unsafe act from a willful violation to a knowledge-based decision error. This distinction is often difficult for investigators/auditors to accept; but, keep in mind that violations in this sense represent the willful disregard for the rules which implies knowledge.

Routine Violations

- Routine violations can be viewed as a “bending” of the rules. They are usually a habitual deviation from the rules and tend to be tolerated by management.
- A factor in an incident when an employee regularly shows disregard for rules and regulations and results in or contributes to an unsafe situation.

Exceptional Violations

- Exceptional violations are isolated deviations from the rules, but are not tolerated by management.
- Factors in an incident when an employee shows extreme disregard for rules and regulations and results in or contributes to an unsafe situation.

2. Preconditions for Unsafe Acts

Certainly, the unsafe acts of operators can be directly linked to nearly 80% of all incidents/accidents. However, simply focusing on unsafe acts is like focusing on a fever without understanding the underlying illness that is causing it. Thus, managers, safety professionals, and investigators/auditors must dig deeper into why the unsafe acts took place.

The process involves analyzing preconditions of unsafe acts, which includes the condition of the operators, environmental and personnel factors. Fig. A.2 shows brief description of “Preconditions for Unsafe Acts.

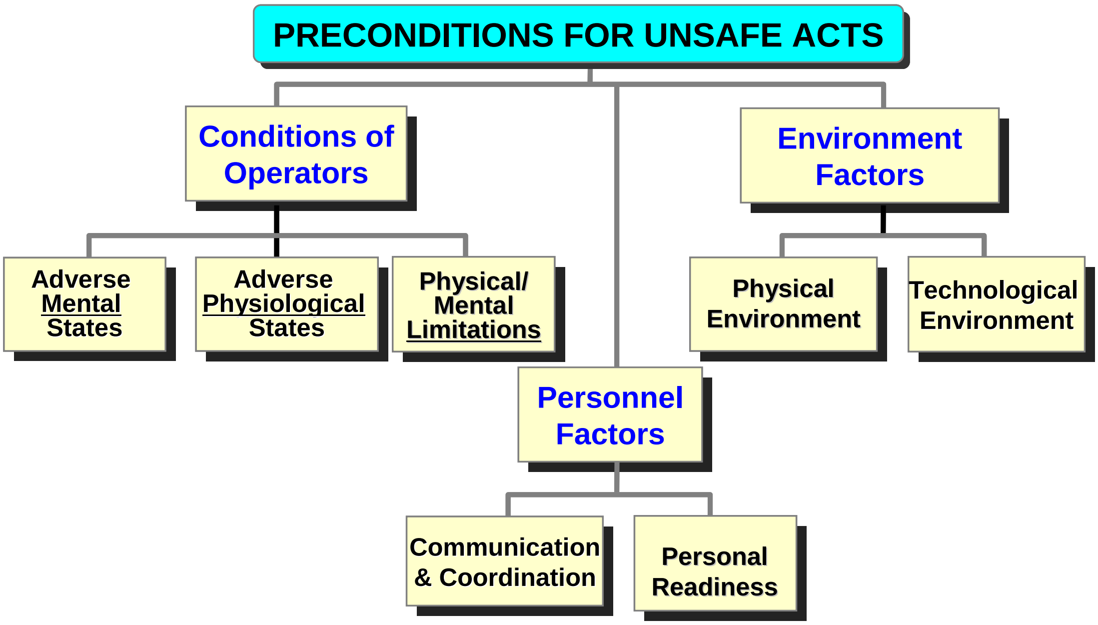

Fig. A. 2. HFACS-Preconditions for Unsafe Acts

2.1. Condition of Operators

The condition of an individual can, and often does, influence his/her performance on the job. Unfortunately, this critical link in the chain of events leading up to an accident (or non-Conformance, or safety related concern) often goes unnoticed by managers, safety professionals, and investigators/auditors who may have received little formal training in human factors, psychology, or aerospace medicine. The following are three conditions of operators that directly impact performance:

Adverse Mental States

- Adverse mental state factors account for those mental conditions that affect performance.
- Principal among these is the loss of situational awareness, task fixation, distraction, and mental fatigue due to sleep loss or other stressors.
- Also included in this category are personality traits and pernicious attitudes such as overconfidence, complacency, and misplaced motivation.

Adverse Physiological States

- Factors refer to those medical or physiological conditions that preclude safe operations.
- Physical fatigue
- Effects of simply being ill: illness can affect our mood, concentration, and reaction times, not to mention the negative effects of many medications that can make operators drowsy while on the job

Physical/Mental Limitations

- Physical/mental limitations when operational requirements exceed the capabilities of the employee at the controls (lacks the physical or mental capabilities to cope with a situation).

- Typically, these limitations are acquired/present before the event.
- When faced with the need for rapid processing and reaction time (as is the case during most emergencies) all forms of error would be exacerbated.
- Involved individuals who are simply are not compatible with a certain job, because they are either unsuited physically or do not possess the aptitude.

2.2. Personal Factors

Personal Factors include the things that employees often do to themselves unknowingly to create an unsafe situation. It may contribute to an incident if self-imposed stressors or communication problems affect practices, conditions, or actions. These factors can result in or contribute to human error or to an unsafe situation.

Communication & Coordination

- Account for instances of poor communication/coordination within and between work teams, as well as with supervisors, maintenance, and other personnel.
- It also includes coordination before and after work activities

with the pre-work briefing and post-work debriefing of the team.

Personnel Readiness

- Personnel readiness occurs when individuals fail to prepare mentally or physically for duty.
- A factor in an incident if the employee demonstrates disregard for rules and instructions that govern the employee's readiness to perform (e.g., not getting enough rest, excessive drinking while off duty, or self-medicating while ill, can all adversely affect performance on the job).

2.3 Environmental Factors

Describe the system and/or environment an employee could potentially be effected by. It is a factor in an incident if physical or technological factors affect practices, conditions, and actions of an employee. These factors can result or contribute to human error or an unsafe situation.

Physical Environment

- Refer to both the operational environment (cockpit, airport, and etc.) and the ambient environment (weather, geographic, and etc.).
- A factor in an incident if characteristics from the physical

environment affect the actions of the employee.

Technological Environment

- Refer to the operating environment and include tools, objects, automation, and checklists located in that environment.
- Factors include (but are not limited to) design of equipment/material, ergonomics, checklist design, and automation/IT system design.
- Technological environment is a factor in an incident if characteristics from the technological environment effect the actions of the employee.

3. Unsafe Supervision

Supervisors influence the condition of the employees and the operational environment. Supervision is a factor in an incident if a supervisor or middle manager does not meet standards, or tasks are not designed properly, or a known problem or issue is not corrected in a timely manner, or distinct violations of rules and regulations are committed by supervisors. As you seen Fig. A. 3, it can be categorized into four groups: inadequate supervision, planned inappropriate activities, failed to correct problem, and supervisory violations.

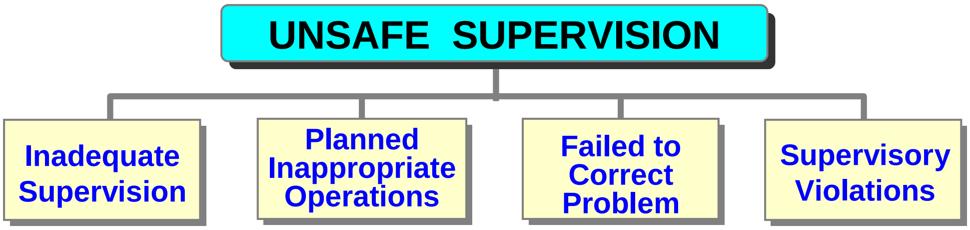

Fig. A. 3. HFACS-Unsafe Supervision

3.1. Inadequate Supervision

A supervisor must provide guidance, training, leadership, oversight, or whatever it takes to ensure the job is done safely and efficiently. This includes providing adequate tools or personnel protective equipment for the job, conducting frequent work walk-through, and effective performance feedback. Inadequate supervision accounts for those times when supervision proves inappropriate, improper, or nonexistent. It is a factor in an incident if a supervisor demonstrates inappropriate or improper characteristics or actions.

3.2. Planned Inappropriate Activities

During a state of emergency, some operations, such as excessive tasking or lack of rest, are unavoidable and will put individuals at unacceptable risk; however, those operations are not acceptable during normal operations. Planned inappropriate activities are a factor in an incident if supervision fails to correctly assess the hazards associated with an operation and allows for unnecessary risk. It also a factor if supervisors allow inexperienced or non-proficient employees or crews to attempt tasks beyond their capabilities. For example, assigning individuals to perform a task for which they are not qualified (Improper matching of qualifications for job) or not clearly communicating or delegating authority to qualified individuals. Furthermore, supervisors may place improper pressure on operators to work at a pace that reduces safety margins or even reinforces taking shortcuts to complete jobs quickly.

3.3. Failed to Correct Problem

It refers to those instances when deficiencies among individual, equipment, training, or other related safety areas are "known" to the supervisor, yet are allowed to continue uncorrected. It is a factor in an incident if a supervisor fails to correct a known problem whether the problem is in documents, process, procedures, or individuals. Indeed, the failure to report these unsafe tendencies and initiate corrective actions is yet another example of the failure to correct known problems.

3.4. Supervisory Violations

Refers to those instances when existing rules, regulations, instructions, guidance, or standard operation procedures are willfully disregarded by supervisors. For instance, there have been occasions when individuals were permitted to operate a piece of machinery without current qualifications or proper training.

4. Organizational Influences

Any decisions of upper-level management can directly affect supervisory practices, as well as the conditions and actions by employees. Organizational Influence is factors in an incident if the communications, actions, or policies of upper-level management affect supervisory practices, environment, and/or actions of the employee and leads to human error or an unsafe situation. As can be seen in Fig. A. 4, Organizational influences can be categorized into three groups: resource management, organizational climate, and organizational process.

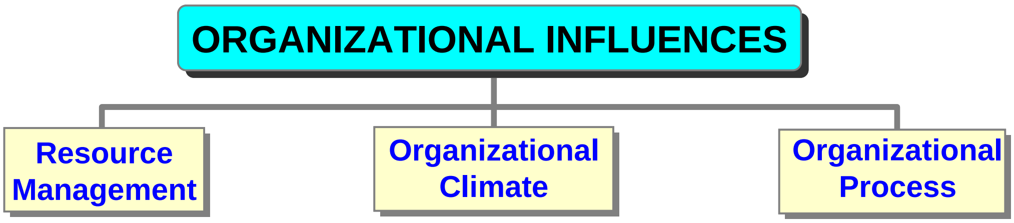

Fig. A. 4. HFACS-Organizational Influence

4.1 Resource Management

It includes the area of corporate-level decision-making regarding the allocation and maintenance of organizational assets such as human resources (personnel), monetary assets, and equipment/facilities.

Resource management is a factor in an incident if resource management influences individual, supervisory, and/or organizational performance and results in a hazard.

Generally speaking, corporate decisions about how such resources should be managed are typically based upon two, sometimes conflicting, objectives – the goal of safety and the goal of on-time, cost-effective operations. When organizations are experiencing financial difficulties, unfortunately, safety and training are often the losers.

For example, excessive cost-cutting could also result in reduced funding for new equipment, the purchase of low-cost, less effective alternatives, or worse yet, the lack of quality replacement parts for equipment. Likewise, in an effort to save money, organizations may purchase vehicles that are improper for their desired use, or choose a vendor that is "cheaper" yet unqualified to provide the proper service. As a result, a supervisor may have no choice but to assign operators to tasks with improper tools, which then leads to unsafe activities on the job.

- Human resources can be classified as the management of personnel (management of training, contractors, etc.).
- Monetary assets can be classified as the management of nonhuman resources (cost cutting, budget/funding, etc.).
- Equipment/facilities can be related to equipment/facilities design, condition and the failure to correct known flaws

4.2 Organizational Climate

The organizational climate can be viewed as the working atmosphere within the organization. It is a factor in an incident if organizational variables influence individual, supervisory, and/or organizational performance and results in a hazard. The climate is reflected in an organization's structure, policies, and culture.

Structure can be classified as the formal arrangement of an organization. It reflected in the chain-of-command, delegation of authority, communication channels, and formal accountability for actions. Just like in the cockpit, communication and coordination are also vital within an organization. If management and staff are not communicating, or if no one knows who is in charge, organizational safety clearly suffers and incident (or non-conformities and safety related concerns) can and will happen.

Policies are official guidelines that direct management's decisions about such things as hiring and firing, promotion, retention, sick leave, and a myriad of other issues important to the everyday business of the organization. When policies are ill-defined, adversarial, or conflicting, or when they are supplanted by unofficial rules and values, confusion abound.

Culture really refers to the unofficial or unspoken rules, values, attitudes, beliefs, and customs of an organization. Put simply, culture is "the way things really get done around here."

4.3 Organizational Process

It refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standard operating procedures and formal methods for maintaining checks and balances (oversight) between the workforce and management.

Organizational process is a factor in an incident if organizational processes negatively influence individual, supervisory, and/or organizational performance and results in a hazard or worse. It can be classified into three areas: operations, procedures, and oversight.

Operations can be classified as the conditions of work that have been established by management. Non-standard procedures and other organizational factors such as operational tempo, time pressures, and work schedules are all variables that can adversely affect safety. When those within the upper level of an organization determine that it is necessary to increase the operational tempo to a point that overextends a supervisor's staffing capabilities, a supervisor may have no recourse other than to utilize Improper scheduling procedures that jeopardize operator rest or produce sub-optimal team compositions, putting operators at an increased risk of an incident (or non-conformities and safety related concerns).

Procedures can be classified as the official standard operating procedures set in place to address how the job is performed (for example, Improper performance standards or unclear definition of objectives could affect safety).

Oversight can be classified as the monitoring and checking of resources, climate, and processes to guarantee safety. Regrettably, however, not all organizations have these procedures nor do they engage in an active process of monitoring errors and human factor problems via confidential reporting systems and safety audits. As such, supervisors and managers are often unaware of the problems before an incident occurs.

초 록

최근 상업용 항공기는 주문용 오디오 시설 등과 같은 항공여행 편의시설의 발달과 더불어 고도의 새로운 항공기술이 지속적으로 도입되고, 보다 더 복잡한 구조로 급속히 발전하고 있다. 하지만, 상업용 항공에서는 안전이 최우선이다. 어떠한 편의 시설보다, 가장 궁극적인 항공교통의 목적은 안전하게 승객을 목적지까지 수송하는데 있다.

지속적인 항공 교통량 증가 추세를 고려하면, 미국의 경우, 향후 15년 이후 교통량이 두 배 증가함에 따라, 사고건수도 두 배로 증가 할 수 있다는 것을 쉽게 예상할 수 있다. 다이나믹한 항공산업의 환경변화 속에서 그 동안, 항공기 기술 개발 및 시스템개선으로 신뢰성이 개선되고 사고율도 감소 할 수 있었지만, 새로 도입되는 시스템과 상호 작용하는 조직과 인적 요소 부문이 사고의 근본원인으로 부각되고 있다. 이러한 환경변화를 고려하고, 체계적인 안전관리 관리와 개선을 위해서, 국제민간항공기구 (ICAO: The International Civil Aviation Organization) 는 안전관리시스템 (SMS: Safety Management System)을 수립하였으며, ICAO 체결국가들이 이행 하도록 규정하였다. 이에 따라 항공사, 공항, 항공관제, 항공기 정비조직, 교육기관에 대한 SMS 도입이 먼저 의무화 되었고, 마지막으로 항공기 제작산업분야로 확대되어 항공기 디자인 단계부터 항공산업 전반에 걸쳐 안전을 통합관리하기 위한 방안으로 제시되었다. 항공기 설계, 제작, 운용 중

발생 될 수 있는 잠재적인 문제점을 발췌하여 수정 및 안전 개선 작업을 통해서 사전에 예방할 수 있다면 막대한 인적, 물적 자원 절감에 기여할 수 있다. 항공기 설계 및 제작단계에서부터 체계적인 안전관리를 통한 안전성 제고는 결국 글로벌 항공시장에서의 경쟁력강화로 이어 질 수 있다.

대부분 품질관리시스템 (QMS: Quality Management System)에 익숙하고 잘 이행하고 있는 항공 제작산업분야에서는 SMS의 필요성 및 혜택에 대해서 잘 인지하지 못하고 있다. 항공기 개발단계에서부터 체계적인 안전위험 관리는 항공기 인가, 인증 시 누락될 수 있는 안전위험을 최소화 하고 완성된 항공기가 운항을 시작하여 발생되는 결함으로 인한 재설계, 수정작업에 드는 막대한 비용을 줄일 수 있다.

본 연구에서는 항공기 제작분야에서 SMS를 도입해야 하는 중요성에 대해서, 기존의 QMS와의 차이점을 확인하고, MD-11 항공기 사고사례 연구 분석을 통해서 명확하게 제시 하였다. 항공기 사고 사례에 대한 분석은 사고의 근본원인을 분석하기 위한 Human Factor Analysis and Classification System(HFACS) 와 위험레벨 분석을 위한 FAA Transport Airplane Risk Assessment Methodology (TARAM) 모델을 사용하였다. 분석을 통해, 항공기 제작단계에서의 발췌된 안전위험에 대해서 어떻게 관리하고, 또한 완성된 항공기가 운항 시 이러한 안전위험이 어떻게 연계하여 관리되는가에 따라 안전운항 및 항공기 라이프 사이클에도 중대한 영향을 끼치는 것을 확인 하였다

궁극적으로 항공기 제작산업 분야에서 SMS의 효율적인 이행 여부는 글로벌 항공시장의 경쟁력이 될 수 있다. 이에 본 연구 마지막 단계에서는, 실제적인 SMS 적용과 항공기 사고예방을 위해서 안전위험관리 측면에서 기존의 QMS 와 통합할 수 있는 효율적인 SMS 이행 방안을 제시 하였다.

Keyword : 안전관리 시스템, 항공기 제작산업, 설계, 인증 절차, 인적요인 분류 분석 시스템, 위험관리, 사고예방

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