國立成功大學
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博士論文

臺灣航空器事故模型分析暨
機場安全管理系統績效評估

Analysis of Aircraft Accident Model and Performance

Evaluation on Airport Safety Management System in Taiwan

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摘 要

航空失事可能導致死亡與巨額損失，在 2001 年至 2010 間，根據台灣民航局 2011 年的統計，其國籍民用航空業之渦輪噴射機類的全毀飛航事故統計中，每百萬離場次數之平均失事率是世界同型機種的 2.3 倍；另一方面，根據台灣飛航安全調查委員會在 2000 年至 2010 年間的統計，參考國際民航組織事故分類，發生頻率最高的最大飛航事件為衝出/偏出跑道類別(Runway Excursion)，與地面碰撞類別(Ground Collision)，顯示了台灣的飛安績效，對國際民航組織在提昇機場安全上，仍有進步的空間，是故，機場安全管理系統(Airport Safety Management System, SMS)的執行，越發顯得格外的重要。

論文主要以 ICAO 事故分類來進行台灣在 1985 年至 2010 年間所發生的飛航事故分類統計，再依據事故類別的數據特性以卜瓦松機率分配 (Poisson probability distribution) 進行分析，繼而利用卜瓦松回歸(Poisson regression)進行影響台灣飛安失事率的各類事故判別。研究結果顯示，影響航空器失事率的前五名事故主類別依序為：(1)起飛、降落與地面作業(Takeoff, Landing, and Ground Operations); (2)航空器(Aircraft); (3)雜項(Miscellaneous); (4)天氣(Weather); (5)航行間 (Airborne)；影響航空器失事率最明顯原因為發生於機場場面的「起飛、降落與地面作業」主類別航空器事故，因此，機場安全管理系統(SMS)作業更顯得重要。為了解台灣機場 SMS 績效，本研究再藉由產、官與學術界的專家學者進行問卷調查，利用分析網路程序法(ANP)獲取各要項與要素的權重，並利用模糊理想解排序偏好法(Fuzzy TOPSIS)進行台灣桃園機場公司、高雄與台北松山國際機場的 SMS 各要項與要素的績效評估與排序，繼而訪談三個機場的高階 SMS 經理，對照績效排序結果進行歸納及驗證。

根據機場 SMS 績效排序研究結果顯示：台灣機場 SMS 整體績效評估依序為桃園、高雄與松山機場。根據訪談的內容與機場 SMS 績效評比結果得知: SMS 要項中的 C_2 安全風險管理，C_3 安全保證與 C_4 安全提升之間存在影響關係；此外，不同的機場性質將影響機場安全政策與安全文化的履行，如: 國有控股機場公司、國營機場、軍用與民用機場，是故，一個提供全方位服務的機場須能快速而有效率的反應機場使用者的需求。研究結果首次揭櫫台灣機場安全管理系統績效評比，並遵循 ICAO 國家民用航空安全計畫(SSP)的安全目標進行研究，除了提供台灣航空主管機關、機場管理單位與航空公司在安全風險管理作業上的方向及資源分配依據外，亦有利安全培訓的發展，降低飛航事故的發生。

關鍵字： 飛航事故、航空器失事、航空器致命事故、卜瓦松回歸、機場安全管理系統、分析網路程序法、模糊理想解排序偏好法。

ABSTRACT

Aviation accidents can cause fatalities and a tremendous loss of property. For the decade from 2001 to 2010, the average accident rate involving turbojet aircraft hull loss in Taiwan exceeded the world average by 2.3 times per million departures, as calculated by the Taiwan Civil Aeronautics Administration (CAA) in 2011. According to the records of Taiwan Aviation Council (ASC) from 2000 to 2010 in Taiwan, the top two rankings for occurrence are Runway Excursion (RE) and Ground Collision (GCOL), which indicated a poor safety performance in comparison with the International Civil Aviation Organization (ICAO) safety targets in reducing runway excursion events and ground collision events. Particularly these two categories of occurrences happened at the ground of airports, therefore, the airport Safety Management System (SMS) is extremely important.

This research is divided into two parts, the first part is to determine the pattern of aviation accidents, and to use ICAO occurrence categories to describe the classification of aviation occurrences (accidents, serious incidents and fatal accidents) in Taiwan from 1985 to 2010. Then, based on the data, Poisson probability distribution is used to describe pattern of the number of occurrences, and then Poisson regression is used to determine the importance of the ICAO occurrence categories. The most significant occurrences were (in descending order): (1) Takeoff, Landing, and Ground Operations; (2) Aircraft; (3) Miscellaneous; (4) Weather; and (5) Airborne.

Based on the results of part one research, the category of Takeoff, Landing, and Ground Operations is the most significant occurrence which often happens at the ground of airport. Thus, airport safety is extremely important. In order to know the performance of airport Safety Management System (SMS) in Taiwan, the airport SMS performance was evaluated by the experts of airline industries, government and academic area via questionnaire survey. This study acquires the weights and rankings of the SMS components and elements via Analytic Network Process (ANP) method, and afterward the fuzzy Technique of Ordering Preference by Similarity to Ideal Solution (fuzzy TOPSIS) method is used to evaluate and rank the SMS performance of Taiwan Taoyuan (TPE), Kaohsiung (KHH) and Taipei Songshang (TSA) international airports. Finally, the rankings of these airports are determined.

Based on the results of overall airport SMS performance, the rankings of three international airports are in the order of TPE, KHH and TSA. According to the interview with top SMS managers, the performance evaluations of three airports are affected by the three components, C_2 (*Safety risk management*), C_3 (*Safety assurance*) and C_4 (*Safety promotion*).

Since the nature of an airport can affect the implementations of safety policy and safety culture, such as government-owned incorporated, governmental, civil-military airports do, a full-service airport shall efficiently respond to the requirements of stakeholders under dynamic and uncertain situations.

The findings of this research are the first time in Taiwan to uncover the airport SMS performance ranking to comply with ICAO SSP safety targets, and the results can provide aviation authorities, airport administrators and airlines companies in Taiwan with a direction for safety risk management and allocation of materials and resources to conduct safety training in order to prevent aviation occurrences from happening.

Keywords: Occurrences; Accidents; Fatalities; Poisson regression; Airport SMS; ANP; Fuzzy TOPSIS.

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2008 年是憂喜參半的一年,服務了十二年的遠東航空公司因財務危機而停止營運，在遠航歇業的同時，珮琪考上成功大學交通管理科學研究所攻讀博士學位。

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老子曰:「合抱之木，生於毫末；九層之臺，起於累土；千里之行，始於足下」;學習的過程是一點一滴的累積與反省，在這條研究跑道的起始點，珮琪感謝碩士學位的指導老師：海洋大學顏進儒教授、余坤東教授以及計量方法指導老師梁金樹教授的啟蒙與引導，為珮琪奠定了研究能力的基礎；而在遠東航空公司的部分，感謝航務處總機師李如安教官的栽培與推薦，航務處性能發展科蔡憲偉主任的專業諮詢，在後續飛航實務與安全管理的研究上，兩位成為最專業的後盾；本人也特別感激遠東航空的專業訓練，十二年的航空公司實務經驗，亦成為珮琪寶貴的研究素材。

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ACRONYMS AND ABBREVIATIONS

ALos	Acceptable Level of Safety
ASC	Aviation Safety Council
ARC	Abnormal Runway Contact
CAA	Civil Aeronautics Administration
CABIN	Cabin Safety Events
CFIT	Controlled Flight into/ toward Terrain
GOCL	Ground Collision
ICE	Icing
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
FAA	Federal Aviation Administration
F-NI	Fire/Smoke (Non-Impact)
FOD	Foreign Object Damage/Foreign Object Debris
KHH	Kaohsiung International Airport (IATA airport code)
OTHR	Other
RAMP	Ground Handling
RE	Runway Excursion
RI-VAP	Runway Incursion/Vehicle, Aircraft or Person
SARPs	Standards and Recommended Practices
SCF-PP	System/Component Failure or Malfunction (Power plant)
SCF-NP	System/Component Failure or Malfunction (Non- Power plant)
SMM	Safety Management Manual
SMS	Safety Management System (s)
SRM	Safety Risk Management
SSP	State Safety Program
TPE	Taoyuan International Airport (IATA airport code)
TSA	Taipei Songshang Airport (IATA airport code)
TURB	Turbulence Encounter
USOS	Undershoot or Overshoot
WSTRW	Windshear or Thunderstorm

Chapter 1 Introduction

1.1 Research Background and Motivation

Between 2001 to 2010, the average accident rate per million departures in Taiwan involving turbojet aircraft hull loss was 2.3 times the world's average (Civil Aeronautics Administration (CAA) (2012); the average rate of hull loss occurrences on commercial jets was 1.75 per million departures and on turboprop aircraft was 1.25 (CAA) (2012). The International Civil Aviation Organization's (ICAO) (2009a) recommended the safety targets include reduction in fatal airlines accidents, serious incidents, runway excursion events and ground collision events, and then the safety targets was set out in Taiwan CAA (2011a); finally, the State Safety Program (SSP) was implemented on December 17, 2012.

According to the ICAO Occurrence Categories (ICAO, 2008) and Taiwan Aviation Safety Council (ASC) Accident/Serious Incident classification, this study looks back to the aviation safety statistics from 2000 to 2010 in Taiwan (ASC, 2012), the top one occurrence is Runway Excursion (RE) with 10 frequencies and top 2 is Ground Collision (GCOL) with 3 frequencies, which indicated a poor safety performance in comparison with the ICAO safety targets in reducing runway excursion events and ground collision events (ICAO, 2009a) (CAA, 2011a) (Shao et al., 2013). Particularly these two categories accidents happened during aircraft take-off and landing phases at an airport surface, and the runway safety is the "one of aviation's greatest challenges worldwide" (United States Federal Aviation Administration (FAA), 2010). Based on the perspective of airport safety (including runway safety), the airport Safety Management System (SMS) is extremely important.

Refer to the Taiwan's SSP (CAA, 2011a), airport service shall demonstrate their management system adequately to reflect an SMS approach which includes improved safety management, safety practices and safety reporting within the civil aviation industries. So, what is SMS? According to the ICAO Safety Management Manual (SMM) (ICAO, 2009a), SMS is defined as:

An SMS is a management tool for the management of safety by an organization.

In order to approach the safety targets including reduction in fatal airlines accidents, serious incidents, runway excursion events and ground collision events, this research look back the holistic aviation occurrence record of Taiwan and to analyze the occurrences categories in which the occurrence rate is affected. Since runway excursion events and ground collision events are related to airport safety, airport practical SMS operations not only comply with ICAO requirements but also improve airport safety. But how well is the airports' SMS in Taiwan? For the motivations, this research is divided into two parts to investigate the safety overview by accident statistics and airport SMS performance (See Fig. 1-1 and Fig. 1-2).

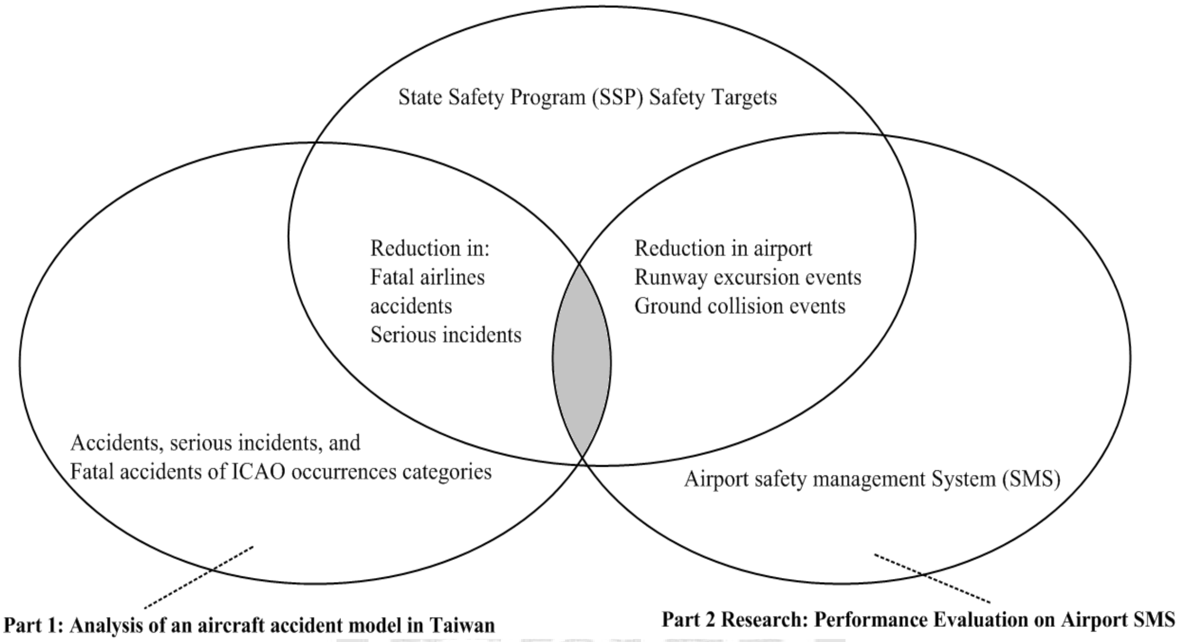


Fig. 1- 1 Conceptual research framework

- **Part one: Analysis of an aircraft accident model in Taiwan**

This research pay more attention to at the causes of these events and tries to find out how they relate to the safety targets set out in Taiwan's Civil Aviation Administration's (2011) Sate Safety Program (SSP) using the fixed-wing aircraft investigation reports of aviation accidents in which the aircraft were registered in Taiwan. These accidents are classified according to the International Civil Aviation Organization Aviation Occurrence Categories (AOC) (ICAO, 2008). Refer to the past research, the air accident data are random and rare (Jovanis and Chang, 1986; Lord and Mannering, 2010). Golbe (1986), Rose (1990), Raghavan and Rhoades (2005) utilized accident rates to evaluate airline profitability and safety performance via the Poisson probability distribution and the Poisson regression. Based on the nature of air accident data, this study uses Poisson regression to analyze the relationship between the causes and accident rate, serious incident rate, and fatal accident rate.

- **Part two: Performance Evaluation on Airport Safety Management System**

Since RE and GCOL accidents are often happened in airport surface, and these two categories are the top two occurrences from 2000 to 2010 in Taiwan, thus, airport SMS is extremely important. In order to the events of RE and GCOL evens via airport SMS operations, the research in Part two intends to review the international airport SMS regulations and patterns, to determine the components and elements, and then to obtain the weights of components and elements via Analytic Network Process (ANP) method.

In the past SMS academic research for aviation industries, most of them were to establish or to discuss airlines SMS components and elements (McDonald et al., 2000; Liou and Yen, 2008; Hsu, 2010), fewer studies are related to airport surface safety indicator and airport SMS (Cardoso et al., 2008; Wilke et al., 2012). Because the airport SMS is important for SSP and there is few research to evaluate the performance, it is appropriate to classify the subject of the airport SMS performance evaluation into a Muti-Attribute Decision Making (MADM) problem according to the nature of research via literature reviewing (Chen and Hwang, 1992; Pohekar and Ramachandran, 2004). For these reasons, Part two research uses the fuzzy Technique of Ordering Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) to evaluates Taiwan Taoyuan, Kaohsiung and Taipei Songshang international airport SMS performance and compares these airports SMS performance via and the weighted average methods. Finally, this research finds the order of their SMS performance. Based on the results, the research in Part two is also to interview airport SMS top managers of Taiwan Taoyuan, Kaohsiung and Taipei Songshang international airport and then draw a conclusion by the findings.

1.2 Research Purpose

Based on research background and motivation, the purposes of Part one and Part two are listed below:

- **Part one: Analysis of an aircraft accident model in Taiwan**

1. To establish Poisson regressions for the aviation occurrences based on the ICAO aviation occurrence categories for the aviation data in Taiwan from 1985 to 2010.
2. To fit Poisson regressions to the Taiwan aviation occurrence data so that this study can analyze the relationship between the Taiwan aviation occurrences and the ICAO occurrence categories.
3. To prove that the Poisson regression model is an appropriate model for aviation accident data, and to compare it with binomial, negative binomial regression models.

- **Part two: Performance Evaluation on Airport Safety Management System**

1. To identify the airport SMS components and elements.
2. To assess the weights of the airport SMS components and elements.
3. To evaluate the international airport SMS performance in Taiwan
4. To rank or order international airport SMS performance in Taiwan.
5. To discuss the current airport SMS operations in Taiwan and to confirm/verify the results in Part two.

1.3 Research Scope

Based on research purpose of Section 1.2, the research scopes of this study are shown as follows:

- **Part one: Analysis of an aircraft accident model in Taiwan**

This research uses the aviation statistics reported from 1985 to 2010 by the CAA and ASC in Taiwan and to review the fixed-wing aircraft investigation reports of aviation accidents in which all involved aircrafts were registered with Taiwan. In Part one research, the ICAO Aviation Occurrence Categories (ICAO, 2008) are used to classify the aviation occurrences in Taiwan via Poisson distribution and Poisson regression by SAS soft ware.

- **Part two: Performance Evaluation on Airport Safety Management System**

In Part two research, the two stages of expert questionnaire survey were undergone from September 8, 2012 to October 30, 2012 and the experts involved in the survey are in groups of airlines industry, government, and academic area with average working seniority of over seventeen years. This study chooses Taoyuan, Kaohsiung and Taipei Songshang international airport in Taiwan for the empirical study. After the second questionnaire survey, a face-to-face interview with three international airport's top SMS managers with over twenty years working seniority are held on March 6 and 8, 2013.

1.4 Research Framework

There are two parts constructed in this research: Part one is dealing with the Analysis of an aircraft accident model in Taiwan, and Parts two is the Performance Evaluation on Airport Safety Management System; the contents of this thesis consist of five chapters, they are: Introduction, Analysis of an Aircraft Accident Model in Taiwan, Reviews of International Airport Safety Management System, Performance on Airport SMS, and Discussions and Conclusions. The sections of literature review, methodology and results are included in Chapter 2, Chapter 3 and Chapter 4, respectively. The overall research framework is shown as Fig. 1-2.

Refer to Fig.1-2, the research of Part one is to uncover the relationship between aviation occurrence categories and the occurrence rate from the Taiwan occurrence data, this study used the International Civil Aviation Organization’s (ICAO) *Aviation Occurrence Categories* (ICAO, 2008) to describe the end states of aviation occurrences (accidents, serious incidents, and fatal accidents) and to model the pattern of aviation occurrences for the data in Taiwan from 1985 to 2010. In Part one, Poisson probability distribution is appropriate for modeling the occurrences, and it is the best means for describing the frequency or probability of such occurrences. There are four sections to be considered in Part one, they are Introduction of Aviation Accident, A Study of Taiwan Aviation Safety Record, Methodology and Empirical Study and Summary.

Based on the results of research in Part one, the significant categories of occurrence, accident, serious incident and fatal accident rate are determined. Due to some categories are often occurred in airport surfaces, the results of the research in Part one can be referenced to support the importance of airport safety management (SMS). In Part two, the performance evaluation components and elements on an airport SMS are established by reviewing the ICAO, Taiwan CAA, and United States FAA certificated airport regulations and manuals. There are two stages for the airport SMS performance evaluation process, at stage one, this study develops the airport SMS components and elements via expert's interview and uses ANP method to obtain the weights of the airport SMS components and elements. In stage two, the fuzzy TOPSIS method is utilized to produce the rank of airport SMS performance for Taoyuan, Kaohsiung and Taipei Songshang international airport in Taiwan. Based on the results of stage two, three top international airport SMS managers were interviewed in order to confirm and verify the ranking of SMS performance obtained earlier. In Chapter 3, this study reviews the literature of SMS, ICAO SMS, international airport SMS implementations and academic research. Under Chapter 4, the methodologies are introduced (ANP, Fuzzy set and fuzzy TOPSIS) and the definitions of airports SMS and empirical study are completed.

Finally, the conclusions of research Part one and Part two are discussed in Chapter 5. The discussions of this research include the research contributions and restrictions. The References and Appendices are posted at in the end of this thesis. There are five Appendices in this research, they are: ICAO Sample Operation Grouping Categories, Framework for ICAO Certified Aerodrome SMS, The first stage experts’ questionnaires, the second stage experts’ questionnaires and the questions and answers for A, B, and C international airport SMS operations.

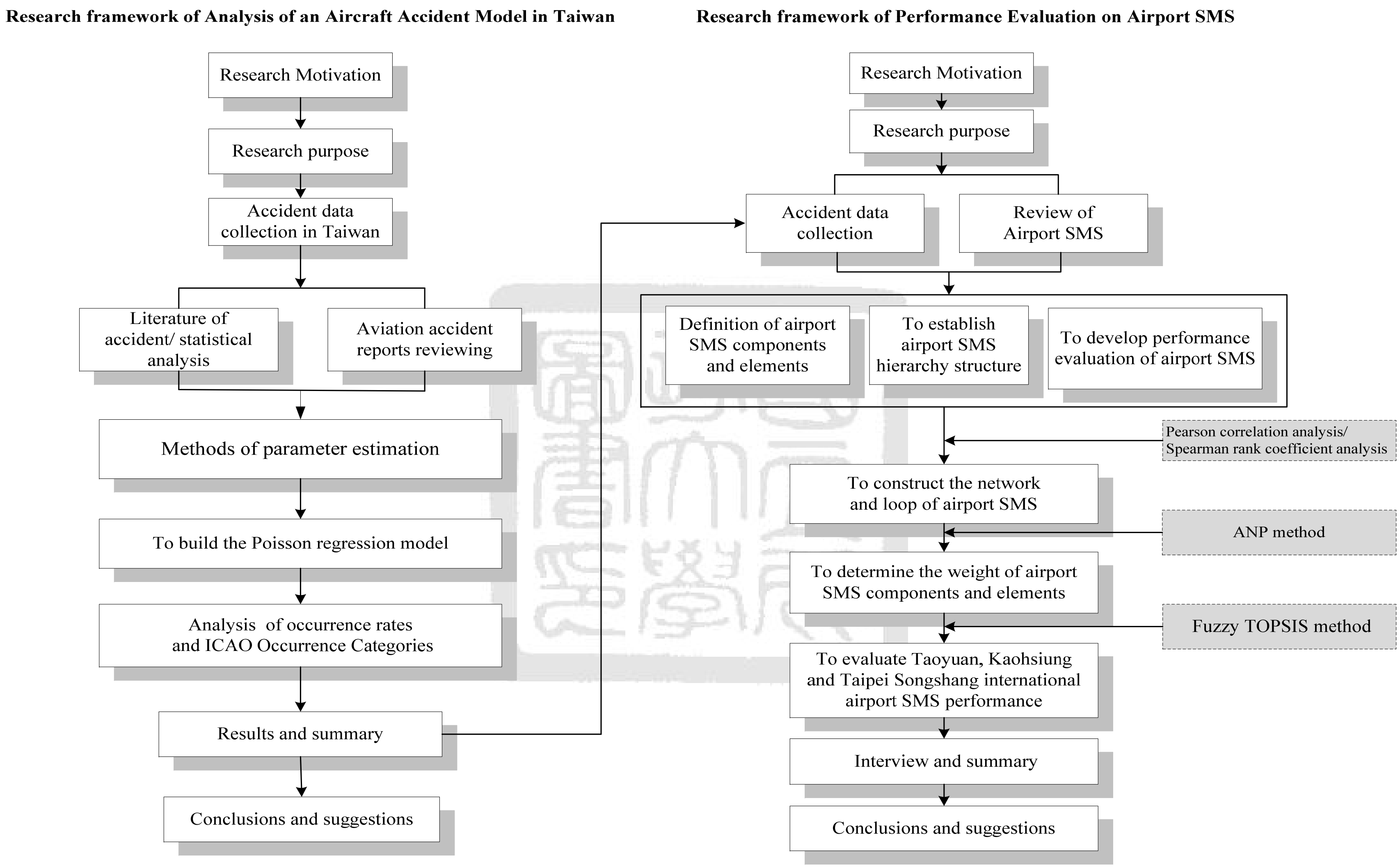


Fig. 1- 2 Research framework

Chapter 2 Analysis of an Aircraft Accident Model in Taiwan

Air accidents are significantly important in air transportation, and they are closely connected to a serious loss of human life. For this reason, air safety is always a critical element to an operational success of the aviation industry, as argued by Chang and Yeh (2004) and others. From the years 2001 to 2010 in Taiwan, the decade average accident rate per million departures of turbojet aircraft hull loss exceeded the world average by 2.3 times (Civil Aeronautics Administration (CAA), 2012). According to the safety statistical data by CAA (2012), the average rate of hull loss occurrences on commercial jets was 1.75 per million departures and 1.25 per million departures on turboprop aircrafts for the period between 2001 and 2010. Based on the investigation safety records in Taiwan, this study further investigates the categories of aviation accidents, serious incidents and fatal accidents by the final reports of the CAA and the Aviation Safety Council (ASC) in Taiwan from the years 1985 to 2010 in order to classify causes of accidents and to recommend aviation safety categories to administrators to pay more attention to the safety problems and to prevent aviation accidents from happening.

In order to uncover the relationship between aviation occurrence categories and occurrence rate from the Taiwan occurrence data, this study utilizes the International Civil Aviation Organization (ICAO) Aviation Occurrence Categories (2008) to describe the end states of aviation occurrences (including accidents, serious incidents and fatal accidents) and to model the pattern of aviation occurrences for the data in Taiwan from 1985 to 2010. Due to the fact that air accident data are random and their occurrences are rare (Jovanis and Chang, 1986; Lord and Mannering, 2010), the Poisson probability distribution is appropriate to model the occurrences, and it is the best means by which to describe the frequency or probability of such occurrences. Traditionally, in the area of transportation accident research, the Poisson probability distribution has been applied to traffic studies since the 1930's (Alghamdi, 1993). Golbe (1986), Rose (1990), Raghavan and Rhoades (2005) utilized accident rates to evaluate airline profitability and safety performance via the Poisson probability distribution and the Poisson regression. When dealing with the aviation occurrence data, little research has been seen on the occurrence data in conjunction with ICAO occurrence categories via the Poisson model.

In order to discuss the airline occurrence rate thoroughly, this study uses a Poisson distribution to model the Taiwan's historical aviation accidents, serious incidents and fatal accidents, and it is shown that the Poisson regression is the most appropriate model among many others for fitting the Taiwan aviation accident data due to the its relation to Poisson distribution. Subsequently, a number of Poisson regressions of the aviation occurrences on the ICAO aviation occurrence categories are established for the aviation data in Taiwan from 1985 to 2010. Thus, our main objectives of this research are to fit a number of Poisson regressions to the Taiwan aviation occurrence data, in order to analyze the relationship between Taiwan aviation occurrences and the ICAO occurrence categories. Finally, this study wishes to recommend the research findings to the air transport authorities and airline top managers in order for them to develop relevant safety procedures intended to prevent aviation accidents from happening via airline safety management in Taiwan.

2.1 A Study of Taiwan Aviation Safety Record

In this study the aviation statistics reported by the CAA and ASC in Taiwan over the period from 1985 to 2010 is used. The accidents, serious incidents, fatal accidents, total departures, accident rates, occurrence rates and fatal accident rates by fixed-wing aircrafts are summarized in Table 2-1. This study first collects the fixed-wing aircraft investigation reports of aviation accidents by ASC in Taiwan during the years from 1985 to 2010, where all aircrafts were registered with Taiwan, and then the five ICAO grouping Aviation Occurrence Categories (ICAO, 2008) are used to classify the occurrences by the CAA and ASC. In summary, there were 52 aviation occurrences by fixed-wing aircraft in Taiwan including 32 accidents with 14 being fatal accidents in the accident group and 20 serious incidents, which can be seen in Table 2-1.

Based on the report of ASC (2009), the number of air transport traffic passengers has grown to fifty million since the air deregulation of 1987 in Taiwan. Further, during the period of 1996 to 1999, the number of fatal accidents, including those occurring in both international and domestic airports, rose higher relative to other years. Before 1999, in Taiwan, both the investigation and prevention of the re-occurrence of civil air accidents and incidents were charged under by the CAA. In 1999, the Aviation Safety Council (ASC) was established by Executive Yuan (top administrative ministry) of the Republic of China (R.O.C.). Since then the ASC has been in charge of the investigation operations in conjunction with the ICAO Annex 13-Aircraft Accident and Incident Investigation (ICAO, 2001a). The ASC is a governmental investigative agency whose duties consist of reports of aviation occurrences (aviation accidents, serious incidents and fatal accidents) and aviation management of aircraft including civil aircraft, public aircraft, and ultra-light vehicles (ASC, 2009).

Table 2- 1 Annual Total Occurrences of Accidents/Serious Incidents, Total Departures and Accident/Occurrence/Fatal Rates from 1985 to 2010

Year	Occurrences [a]		Fatal Accidents	Total Departures (10^4)	Accident [c] Rate	Occurrence [d] Rate	Fatal [e] Accident Rate
	Accidents [b]	Serious Incidents					
1985	1	0	0	7.2101	0.139	0.139	0.000
1986	1	0	1	7.1557	0.140	0.140	0.140
1987 [f]	0	0	0	7.9880	0	0	0
1988 [f]	0	0	0	8.8747	0	0	0
1989	1	0	1	11.7445	0.085	0.085	0.085
1990 [f]	0	0	0	12.5912	0	0	0
1991	1	0	1	15.8741	0.063	0.063	0.063
1992 [f]	0	0	0	18.8908	0	0	0
1993	2	0	0	21.0651	0.095	0.095	0
1994	1	0	1	22.1306	0.045	0.045	0.045
1995	1	0	1	29.1817	0.034	0.034	0.034
1996	1	0	1	33.4692	0.030	0.030	0.030
1997	1	0	1	36.4678	0.027	0.027	0.027
1998	2	0	2	32.6166	0.061	0.061	0.061
1999	3	0	2	33.2466	0.090	0.090	0.060
2000	1	3	1	30.7042	0.033	0.130	0.033
2001	2	1	0	27.717	0.072	0.108	0
2002	2	3	2	27.6167	0.072	0.181	0.072
2003	1	2	0	26.3311	0.038	0.114	0
2004	1	1	0	27.338	0.037	0.073	0
2005	3	1	0	29.2794	0.102	0.137	0
2006	1	1	0	26.4551	0.038	0.076	0
2007	2	1	0	24.8077	0.081	0.121	0
2008	3	3	0	20.8861	0.144	0.287	0
2009	0	1	0	19.5601	0	0.051	0
2010	1	3	0	20.9381	0.048	0.191	0
Total	32	20	14	580.1402	1.474	2.279	0.651
Mean	1.231	0.769	0.538	22.313	0.055	0.088	0.029
S.D.	0.908	1.107	0.706	8.843	0.045	0.068	0.038
Range	3	3	2	29.312	0.144	0.287	0.140

[a] Fixed-wing aircrafts include Turbojet engine aircrafts and Turboprop aircrafts.
[b] Accidents include fatal accidents.
[c] Accidents divided by total departure.
[d] Occurrences divided by total departure.
[e] Fatal accidents divided by total departure.
[f] No occurrence.

The main missions of the ASC are to find causes and contributing factors via air accident investigations and to propose safety recommendations to its top administrators. This study uses the CAA and ASC investigation reports to classify the aviation occurrence categories in accordance with the ICAO's classification standard (ICAO, 2008). So, the civil aircraft (fixed-wing aircraft) accidents and serious incident data are used in our study. Referring to the definition of occurrences by the ICAO, the ASC investigates aviation occurrences (including accidents, serious incidents and fatal accidents) when an occurrence leads to fatality, injury and/or substantial damage to aircraft (ASC, 2009). Due to limited Taiwan accident investigation reports and per hundred thousand departure records, the Taiwan aviation occurrence data recorded by the CAA investigational final reports from the years 1985 to 1998 and by the ASC from the years 1999 to 2010 are used for the purposes of this study.

2.1.1 ICAO Aviation Occurrence Categories

This study utilizes the investigational final reports by the CAA and ASC to classify the end states of occurrences per the ICAO Aviation Occurrence Categories (ICAO, Attachment B, 2008) which is described in the Appendix 1. According to the ICAO Aviation Occurrence Categories, "an occurrence" is defined as "an accident or an incident", and it is focused on powered fixed-wing land and rotorcraft operations; "an accident" is defined as an aircraft accident associated with the operation of an aircraft which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which such person is fatally or seriously injured or in which the aircraft is substantially damaged or missing; "a fatal aviation accident" is defined as an accident which has resulted in one or more passengers dead during the flight from causes of the following: a) a deliberate act by another passenger on the flight, b) a direct hit by any parts of the aircraft, including the sub-part of the aircraft body, c) a direct exposure to turbulent caused by the aircraft and these events exclude deaths due to natural factors, self behavior, others invasion, or hidings of stowaways at non-passengers/crews area on the aircraft in order to travel without paying or without being detected; and finally "a serious incident" is defined as an occurrence of incident associated with the operation of an aircraft which takes place between the times any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, which may cause aviation accidents (ASC, 2009).

Referring to the taxonomies and definitions released by the ICAO occurrence categories, six grouping categories are classified as: (1) Takeoff, Landing, and Ground Operations (TLGO); (2) Airborne (AIRBN); (3) Weather (WTHR); (4) Aircraft (ARCFT); (5) Miscellaneous (MISCN); and (6) Non-aircraft-related (NARCFT). Under each grouping category there are several subcategories; descriptions and their acronyms are tabulated in the Appendix 1. According to the statistical records from 2001 to 2010 by the ASC (2012), the Runway Excursion subcategory was the first ranking by total occurrences in which there were five serious incidents, and the second ranking included the Abnormal Runway Contact (ARC), Turbulence Encounter (TURB), Other (OTHR) and Fire/Smoke (Non-Impact) (F-NI) subcategory. The ARC subcategory consisted of three accidents and one serious incident, and there were four accidents happened under the TURB subcategory, under the OTHR subcategory there were two accidents and two serious incidents happened, and under the F-NI subcategory there were one accident and three serious incidents happened. The frequency of the entire occurrences (a total of 30 cases) in Taiwan airlines classified by ICAO occurrence categories is shown in Fig. 2-1.

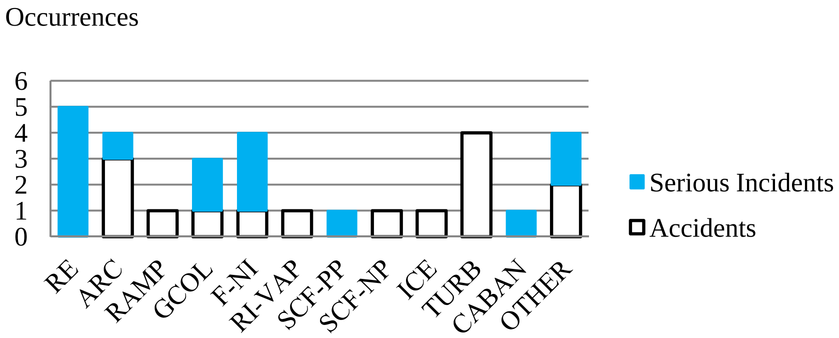


Fig. 2- 1 The Frequency of Occurrences in Taiwan Airlines 2000-2010 (a total of 30 cases) by ICAO occurrence categories (ASC website, 2012)

2.1.2 Aviation Occurrence Data

As pointed out by Sage and White (1980), statistical risk is one type of societal risk that may be determined by the available data on the incidents and accidents in question. Thus, in this study, this research first has used a combined accident and serious incident rate as a measure of safety performance in aviation (Chang and Yeh, 2004). Then this study further considers the accident rate, serious incident rate and fatal accident rate respectively, as measures of safety performance in the analysis of ICAO grouping categories and their subcategories. The aviation data include frequency of occurrences, total departures and rates of occurrences during a period from 1985 to 2010 in Taiwan according to the ICAO Aviation Occurrence Categories (ICAO, 2008). Using the aviation occurrence data, this study employs some statistical methods to build the relationship between the aviation occurrence rate and occurrence categories, and then provide aviation authorities with the findings in order for them to allocate resources necessary to prevent potential aviation accidents in their operations.

2.2 Poisson probability distribution

Due to the fact that air accident data are random and their occurrences are rare (Jovanis and Chang, 1986; Lord and Mannering, 2010), the Poisson probability distribution is the most appropriate model to describe the frequency of accident occurrences for traffic studies (Raghavan and Rhoades, 2005) since its existence in the 1930's (Alghamdi, 1993). Recently, Rose (1990) addressed the problem that the Poisson probability distribution was a natural stochastic model for airline accidents, and the Poisson regression was used to explore the relationship between airlines safety performance and profitability. Other probability distributions, such as binomial and negative binomial by their nature, may also be used to fit the aviation accidental data, but due to the large number of departures compared to a small number of aviation accidents, the binomial and negative binomial distributions converge to the Poisson distribution with negligibly small deviation (Ott and Longnecker, 2010; Washington et al., 2011). Based on the literature referenced above and the nature of accidental data, this study employs the Poisson probability distribution and the Poisson regression to model the air accident occurrences, fatal accidents and serious incidents in the aviation industry.

2.2.1 Fitting a Model

Let the random variable Y (e.g., Y is the number of occurrences in a given year) have the following Poisson probability distribution,

$$P\left(Y=y\right)=\frac{e^{-\mu}\mu^{y}}{y!}, \tag{2-1}$$

where y is a realized value of Y, which may take on values 0, 1, 2, 3,…, and $\mu\,(>0)$ is the average number of accidents or the expected value of Y, usually expressed by $\mu=E(\mathrm{Y})$. Based on the occurrence data in Table 1, the total number of occurrences was 52 (=32+20) over twenty-six years (1985-2010).

By statistical theory, given a set of observed accidental data, if the actual frequencies of the observed accidents are close to these of the expected ones under the Poisson probability distribution (Gupta, 1977), one can claim that the data follow a Poisson probability distribution. For this reason, one may use the Pearson's Chi-square goodness-of-fit test to check if the entire data-set over twenty-six years follows a Poisson probability distribution. That is, to test the null hypothesis H_0: The observed aviation occurrences follow a Poisson distribution versus the alternative H_1 : The observed aviation occurrences do not follow a Poisson distribution. Then the following Chi-square goodness-of-fit test statistic is used to test the hypotheses H_0 versus H_1 as given below:

$$\chi^2 = \sum_{i=1}^{k} \frac{\left(O_i - \hat{E}_i\right)^2}{\hat{E}_i}, \tag{2-2}$$

where k represents the number of groups of occurrences $(0,1,2,\cdots,6,>6)$, O_i and $\hat{E}_i$ represents, respectively, the observed and the estimated expected occurrences in the i^{th} group, where $\hat{E}_i$ is calculated by timing the estimated Poisson probability in column (e) of Table 2-2 to the total number of years, 26, where the estimated Poisson probabilities are calculated by replacing μ in (1) by $\bar{y} = 2.00\ (= 52/26)$.

Table 2- 2 Aviation Accident Data in Taiwan (1985-2010)

(a): Number of occurrences	(b): Observed (O_i)	(c): Expected (E_i)	(d): Product $(a)\times(b)$	(e): Estimated Poisson probability
0	4	3.5187	0	0.1353
1	9	7.0374	9	0.2707
2	4	7.0374	8	0.2707
3	4	4.6916	12	0.1804
4	3	2.3458	12	0.0902
5	1	0.9383	5	0.0361
6	1	0.3128	6	0.0120
>6	0	0.1179	0	0.0045
total	26	26.00	52	1.0000

When the null hypothesis (H_0) stated above is true, the Chi-square goodness-of-fit statistic (2-2) is distributed approximately as a Chi-square with $(k-2)$ degrees of freedom; two degrees of freedom are lost because the Poisson mean needs to be estimated, and the total number of observed frequencies is equal to the total number of estimated expected frequencies. Using the occurrences data in Table 2-1 and information in Table 2-2, the calculated Chi-square test statistic has a value of 2.43, which is less than the critical values of 9.48 with 4 degrees of freedom $(4=6-2)$ at 0.05 level of significance. Alternatively, the calculated Chi-square test statistic (2-2) carries a p-value of 0.657, which is much larger than 0.05. Therefore, a Poisson probability distribution can well fit the overall data for the aviation occurrences in Taiwan over the years 1985-2010. The frequency of occurrences is demonstrated in Fig. 2-2.

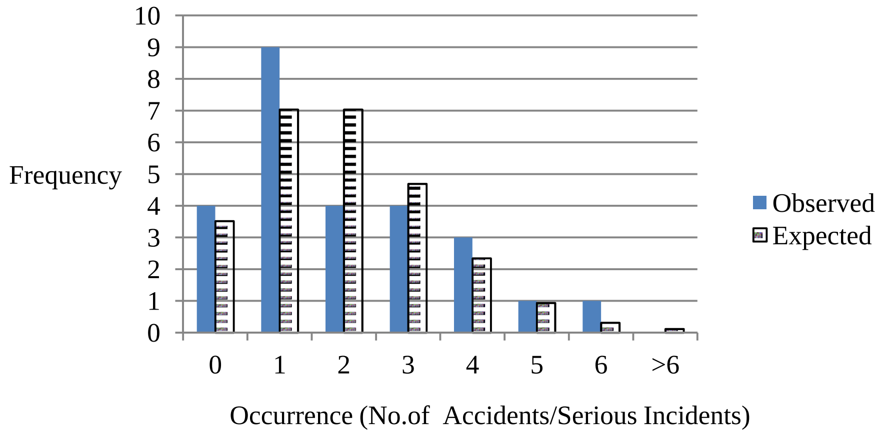


Fig. 2- 2 Occurrence Frequency Trend by Observed versus Expected in Taiwan (1985-2010)

2.2.2 Over- or Under-dispersion Test

Under the Poisson probability model for the number of occurrences, its mean and variance must be equal and, in addition, its mean can be expressed by a regression equation. Thus, if the variance is larger than the mean, the sample data is said to be over-dispersed, and if it is smaller than the mean, the sample data is said to be under-dispersed. If either over-dispersed or under-dispersed variance occurs, the Poisson model may not quite suitable. Under such situations, adjustment must be done via a rescale in advance in order to obtain more accurate standard errors of the estimated Poisson regression parameters and subsequent *p*-values.

In this study, using the data in Table 2-1, the estimated mean of μ is the average number of occurrences, $\bar{y} = 2.00$, and the estimated variance is calculated according to the estimated Poisson probability (as shown in column (*e*) of Table 2-2) of aviation occurrences at the group value of y. Using Table 2-2, the estimated variance of Y is 1.984, and then the ratio of the variance over the mean is 0.992, that is slightly less than one, which may indicate some under-dispersed status. In such situation, one may consider to test for over- or under-dispersion, a regression-based test for testing if the Poisson variance is larger (smaller) than its mean, or over-dispersion (under-dispersion) is used. The method is to fit a regression by the model

$$(Y_i - \mu_i)^2 - Y_i = \alpha \cdot g(\mu_i) + \varepsilon_i \tag{2-3}$$

to see if $\alpha = 0$ where $g(\mu_i) = \mu_i^2$ (Cameron and Trivedi, 1990, 1998). A *t*-test is employed to perform the test for $\alpha = 0$ in which μ_i is obtained by the maximum likelihood method. If the estimate of α shows a significantly positive (negative) value by a *t*-test, an over-dispersion (under-dispersion) adjustment is needed and it will be adjusted by a generalized linear model (i.e., PROC GENMOD in SAS) with a "DSCALE" option in SAS. This kind of adjustment is carried out through all Poisson regressions under this study.

2.3 Empirical Study and Summary

The number of occurrences by its nature is distributed as a Poisson by Equation (2-1) and it has been proven to be an appropriate model as tested by the goodness-of-fit test using the aviation data given in Tables 2-1~2-2. With a Poisson distribution, let Y_i be the actual number of occurrences, N_i be the total number of departures in hundred thousand, and μ_i be the average number of occurrences during the i^{th} year where i is one of the years 1985 to 2010. One may reasonably treat the mean of occurrences, μ_i to be a positive function of some regression parameters $(\beta_0, \beta_1, \cdots, \beta_k)$ associated with k exogenous explanatory variables $(X_0, X_1, \cdots, X_k)$, where $X_0 = 1$ and the average number of occurrences μ_i is equal to the total number of departures multiplied by the true occurrence rate λ_i per departure, i.e., $\mu_i = N_i \times \lambda_i$, where

$$\lambda_i = \exp\left(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}\right). \tag{2-4}$$

It is well-known that the number of occurrences relative to the total number of departures can be modeled by a binomial or a negative binomial distribution. But, the number of occurrences is very small, a binomial or a negative binomial distribution has a computational difficulty, so this study uses a Poisson distribution as an approximation because the Poisson distribution is a limiting distribution of the binomial and negative binomial distributions as the number of departures (N_i) is large and the probability of a failure (P_i) (an accident rate per departure) is relatively small. Since a large number of departures and a small failure rate (P_i) in the binomial and negative binomial distributions can lead to some computational difficulty, a Poisson distribution has been shown to be an excellent approximation to these distributions (Ott and Longnecker, 2010; Hilbe, 2007). Furthermore, the Poisson regression relating to the Poisson distribution is also an excellent regression model to approximate the binomial and negative binomial regressions under their related distributions. To check the validity of Poisson regression, this study uses SAS procedure "PROC GENMOD" to calculate the log binomial regression, the logistic binomial regression and the log negative binomial regression to check if the log Poisson regression is an appropriate model for use in the research, where the log binomial regression is given by

$$\log P_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}, \tag{2-5}$$

where P_i is an accident rate per departure, the logistic binomial regression is given by

$$\log\left(P_i/(1-P_i)\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki}, \tag{2-6}$$

where $P_i = 1/\left(1+e^{-(\beta_0+\beta_1 X_{1i}+\beta_2 X_{2i}+\cdots+\beta_k X_{ki})}\right)$, and the log negative binomial regression has the same form as the log binomial regression in (2-5). By running the SAS procedure, this study has the following table for the parameter estimates of ICAO's grouping categories.

Table 2- 3 Comparison of Different Regressions for ICAO Occurrence Categories

Variable	Log Poisson Estimate (*p*-v) [a]	Log Binomial Estimate (*p*-v) [a]	Logistic Binomial Estimate (*p*-v) [a]	Log Neg. Bin. Estimate (*p*-v) [a]
Intercept	-12.639 (< .0001)	-12.639 (< .0001)	-12.639 (< .0001)	-12.639 (< .0001)
TLGO	0.413 (0.0001)	0.413 (0.0001)	0.413 (0.0001)	0.413 (0.0313)
AIRBN	0.171 (0.584)	0.171 (0.584)	0.171 (0.584)	0.171 (0.760)
WTHR	0.269 (0.012)	0.269 (0.012)	0.269 (0.012)	0.269 (0.163)
ARCFT	0.404 (0.002)	0.404 (0.002)	0.404 (0.002)	0.404 (0.086)
MISCN	0.381 (0.007)	0.381 (0.007)	0.381 (0.007)	0.381 (0.130)
Goodness of fit [b]	5.6107	5.6107	5.6107	5.6107

Note: [a] The values (*p*-v) in brackets are *p*-values.

[b] Goodness of fit is the value of Pearson Chi-square goodness of fit.

From the Table 2-3, this study can easily see that the parameter estimates of the log binomial regression, the logistic binomial regression, and the log negative binomial regression are exactly the same as those of the log Poisson regression. This is because the SAS PROC GENMOD procedure uses the Poisson regression as an approximation. They produced the same parameter estimates, but only difference is their standard errors due to over- or under-dispersion adjustments which cause slightly different *p*-values (see Table 2-3). Therefore, not only is the Poisson distribution an excellent approximation to the binomial and the negative binomial distributions, but also the Poisson regression is an excellent copy of the binomial and the negative binomial regressions. Similarly, in the subcategory analysis all regression models in (2-4) ~ (2-6) produced the same parameter estimates. Thus, in this and the subsequent sections the Poisson regression is adopted as a model to evaluate the importance of the grouping categories and sub-categories.

2.3.1 Estimation of Poisson Regression on the ICAO Grouping Categories

Using the recorded data from 1985 to 2010 in Taiwan and based on the five ICAO operational grouping categories of occurrences: TLGO, AIRBN, WTHR, ARCFT, and MISCN as exogenous explanatory variables, the maximum likelihood method is employed to produce the estimated regression parameters for Equation (2-4).

By Equation (2-3), the estimate of α is negatively significant $(\alpha = -0.138,\ p\text{ - value} < .0001)$, which means the standard errors of Poisson regression parameter estimates are under-estimated. After the under-dispersion adjustment of standard errors by SAS GENMOD and DSCALE option, the maximum likelihood estimates of all regression parameters are exactly the same using Poisson, binomial and negative binomial regressions and their associated *p*-values are also the same except the negative binomial with a minor different. These estimates are given in Table 2-3, where all parameter estimates are positive, which indicate a positive relationship between occurrences and the five ICAO occurrence grouping categories which means that each grouping category has a positive influence on the occurrences and that they have good explaining ability to the occurrences of accidents in Taiwan aviation during the study period. The two grouping categories, TLGO and ARCFT are very significantly important with *p*-values of less than 0.005. This is consistent with the sequential and partial F-test by SAS GENMOD procedure using type 1 and type 3 options. Based on the parameter estimates in Table 3, the two grouping categories, ARCFT and TLGO, associated with the largest regression coefficients are the top two most important grouping categories for the evaluation of the occurrence rate. In addition, the partial contribution to the occurrence rate by the TLGO is *exp*(0.413) or 1.511, by the AIRBN is *exp*(0.171) or 1.186, by the WTHR is *exp*(0.269) or 1.309, by the ARCFT is *exp*(0.404) or 1.498, by the MISCN is *exp*(0.381) or 1.463, and the total adjustment term is *exp*(-12.639) or 3.243^{-6}.

Among the five grouping categories, TLGO is the most significant grouping category and has the highest effect on the occurrence rate with a positive relationship, and the ARCFT is the second most significant grouping category with a very small *p*-value and it is the second highest effect which explains a high risk happening in the phases of take-off and landing. Under the grouping category TLGO, there were twenty-three occurrences, including accidents and serious incidents, occurring during the period between 1985 and 2010. The causes of TLGO are consistent with the argument by Raghaven and Rhoades (2005) who pointed out that the majority of accidents occur during the take-off and landing phases of flights, which typically involve the highest pilot workload, place the largest stress on the pilots of aircraft, and occur in the most congested areas and at the lowest altitudes.

2.3.2 Takeoff Landing and Ground Operation (TLGO)

Under the TLGO grouping category, ten subcategories RAMP, GCOL, LOC-G, RE, RI-VAP, RI-A, USOS, ARC, F-POST, and EVAC are used as exogenous explanatory variables, among the ten subcategories, the LOC-G, RI-A, F-POST, and EVAC shown no occurrence during study period. The maximum likelihood method is employed to produce the estimated regression parameters for RAMP, GCOL, RE, RI-VAP, USOS, and ARC. By Equation (2-3), the estimate of α is negatively significant $(\alpha = -0.372,\ p\text{ - value} < .0001)$, which means the standard errors of Poisson regression parameter estimates are under-estimated. After the under-dispersion adjustment by SAS GENMOD DSCALE option the regression estimates and related information are shown in Table 2-4, where all parameter estimates are positive, which indicate a positive and significant relationship between the accidents and the five subcategories GCOL, RE, RI-VAP, USOS and ARC; each subcategory has a positive influence on the accident and that they all have good explaining ability to the accidents. The four subcategories RI-VAP, GCOL, USOS and ARC are very significant with *p*-values of less than 0.0005 and the RE subcategory is significant with a *p*-value of 0.0462. This is consistent with the sequential and partial F-test by SAS GENMOD using type 1 and type 3 options. In addition, the partial contribution to the accident rate by the GCOL is *exp*(2.808) or 16.577, by the RE is *exp*(1.056) or 2.875, by the RI-VAP is *exp*(2.914) or 18.430, by the USOS is *exp*(2.774) or 16.023, by the ARC is *exp*(1.946) or 7.000, and the total adjustment term is *exp*(-15.395) or 2.6^{-7}.

Table 2- 4 Analysis of Parameter Estimates for the ICAO Occurrence Categories by Accidents under Takeoff, Landing and Ground Operation

Variable	Estimate of Parameter	Standard Error	Wald Chi-square	*p*-value
Intercept	-15.395	0.560	755.8	<.0001
GCOL	2.808	0.771	13.27	0.0003
RE	1.056	0.530	3.98	0.0462
RI-VAP	2.914	0.771	14.29	0.0002
USOS	2.774	0.674	16.29	<.0001
ARC	1.946	0.329	35.00	<.0001

Based on the findings, RI-VAP has the highest effect on the estimate of the accident rate with a positive relationship. Retracing the causes of RI-VAP occurrences, a number of specific circumstances lead to Runway Incursions which include: (1) confusing airport layouts, (2) visibility limitation, (3) high traffic volume and (4) communication errors (Young and Vlek, 2009). To the search of the causes of GCOL occurrences, the International Air Transportation Association (IATA) (2008) addressed the fact that the factors contributing to Runway Collisions are (1) Latent conditions: deficiencies in regulatory oversight, (2) Threats: environmental factors including wildlife, birds and foreign objects, and (3) Airport facility factors, including poor signage, faint markings and runway or taxiway closure.

For the serious incidents (the third column of Table 2-1) separated from the occurrences of the TLGO grouping category, a Poisson regression of serious incidents on the above subcategories is fitted by the maximum likelihood method. By Equation (3), the estimate of α is negatively significant $(\alpha = -0.257,\ p\text{ - value} < .0001)$, which means that the standard errors of Poisson regression parameter estimates are under-estimated. After the under-dispersion adjustment by SAS GENMOD DSCALE option the regression estimates are shown in Table 2-5, where three parameter estimates associated with the subcategories GCOL, RE and RI-VAP are positive and significant, which indicate positive relationship to the serious incident rate, and each subcategory has a positive influence and good explaining ability to the serious incidents. The results correspond to the safety indices of State Safety Program (SSP) (CAA, 2011) and SMM (ICAO, 2009a) for RE and GCOL.

Table 2- 5 Analysis of Parameter Estimates for the ICAO Occurrence Categories by Serious Incidents under Takeoff, Landing and Ground Operation

Variable	Estimate of Parameter	Standard Error	Wald Chi-square	*p*-value
Intercept	-15.055	0.594	641.76	<.0001
GCOL	2.505	0.686	13.33	0.0003
RE	3.142	0.630	24.84	<.0001
RI-VAP	1.173	0.229	26.30	<.0001

The three subcategories GCOL, RE and RI-VAP are very significant with *p*-values of less than 0.0005, which are consistent with the sequential and partial F-test by SAS GENMOD by type 1 and type 3 options. In addition, the partial contribution to the serious incident rate by the GCOL is *exp*(2.505) or 12.244, by the RE is *exp*(3.142) or 23.15, by the RI-VAP is *exp*(1.173) or 3.231and the total adjustment term is *exp*(-15.055) or 2.90^{-7}.

In relation to the TLGO, the RE subcategory had the highest effect on serious incident rate, and the occurrences of Runway Excursion can happen during the phases of take-off and landing by the IATA (2008) listed contributing factors including (1) Latent conditions: deficiencies in regulatory oversight, safety management, and training systems, (2) Threats including environmental factors: airport facilities, meteorology, and airline factors: aircraft malfunction and maintenances events, (3) Flight crew error relating to manual handling/flight control, SOP adherence/cross verification and callouts, (4) Undesired aircraft states including long, floating, bouncing, firm and off-centre line or crabbed landing/continued landing after unstable approach/vertical, lateral or speed deviations/reject take-off after V1 (decision to take-off speed).

In Taiwan, the most frequent subcategory was RE, with nine times occurred in the past twenty-six years, among which eight were serious incidents. The findings not only comply with the official statistical records from the ASC in 2010 but also can provide airlines managers and authorities with their emphasis on the safety operations, safety education and retraining simulations under various scenarios and weather conditions on the take-off and landing phases. The causes of the other subcategories GCOL and RI-VAP have been addressed in previous paragraphs.

2.3.3 Airborne

According to the ICAO Aviation Occurrence Categories (2008), six subcategories MAC, CFIT, LOC-I, FUEL, LALT and AMAN are under the AIRBN grouping category. Among the four subcategories, MAC, FUEL, LALT and AMAN showed no occurrence during the study period. The CFIT subcategory is the only exogenous explanatory variable for the fatal accidents after this study deletes the insignificant subcategories. By Equation (2-3), the estimate of α is positively significant ($\alpha = -0.555$, p-value $< .0001$), which means the standard errors of Poisson regression parameter estimates are under-estimated. After the under-estimation adjustment to the standard errors by SAS GENMOD DSCALE option, the results are shown in Table 2-6 where the regression parameter estimate for CFIT obtained by the maximum likelihood method is 0.919 with a *p*-value of 0.0595 which means that CFIT has a positive influence on fatal accident and it has good explaining ability to the fatal accidents. Additionally, the partial contribution to the fatality rate by the CFIT subcategory is *exp*(0.919) or 2.507, and the total adjustment term is *exp*(-13.293) or 1.69^{-6}.

Table 2- 6 Analysis of Parameter Estimates for the ICAO Occurrence Categories by Fatal Accidents under Airborne

Variable	Estimate of Parameter	Standard Error	Wald Chi-square	*p*-value
Intercept	13.293	0.345	1485.66	<.0001
CFIT	0.919	0.488	3.55	0.0595

After reviewing the safety record in Taiwan during the study period, all accidents in the CFIT subcategory were fatal accidents, among them two were the most disastrous fatal accidents; the first one was China Airlines flight CI-140 A-300-600R aircraft with 264 dead and 7 injured on April 26, 1994 at Japan’s Nagoya Airport, and the other one was China Airlines flight CI-676 A300B4-622R aircraft, with 202 fatalities including all crew and passengers occurred on February 16, 1998 at Taipei Chiang Kai-Shek International Airport, Taiwan. The cause of the fatal accidents of the CI-140 was mainly due to the fact that the First Officer (F/O) inadvertently activated the GO lever while the crew engaged in the auto-pilot system (APs) with GO AROUND mode during the continuing approach (Aircraft and Railway Accidents Investigation Commission, 1996). The cause of the fatal accidents of the CI-676 was mainly caused by the fact that (1) the aircraft was higher than the normal path during the course of all the descent and approach phases and (2) the crew coordination between the captain and the first officer was inadequate (CAA, 2000).

Investigation of the causes of the CFIT occurrences in the past research has varied with regard to: crew error, communication with Air Traffic Control (ATC) error, poor weather conditions, and/or errors in navigation instrumentation (Breen, 1999). Currently, the prevention of the CFIT mishaps is divided into two directions: (1) offering the crew and the ATC system operation and procedure opportunities via training aids, videos, checklists and procedural recommendations and (2) using on-board devices to detect and warn of impending CFIT mishaps, such as Ground Proximity Warning System (GPWS) (Breen, 1999).

2.3.4 Weather

Under the ICAO Aviation Occurrence grouping category WTHR, three subcategories WSTRW, TURB and ICE are used as exogenous explanatory variables and the maximum likelihood method is employed to produce the estimated regression parameters. By Equation (2-3), the estimate of α is negatively significant ($\alpha = -0.077$, p - value = 0.0607), which means the standard errors of Poisson regression parameter estimates are under-estimated After the under-dispersion adjustment to standard errors by SAS GENMOD DSCALE option, two parameter estimates are positively significant with p-values of 0.0019 and 0.0355, respectively, which indicate a positive relationship of the occurrence rate with the TURB and ICE subcategories as shown in Table 2-7.

This is consistent with the sequential and partial F-test by SAS GENMOD type1 and 3 options. Based on the parameter estimates in Table 6, the ICE and TURB, associated with largest coefficients of 0.498 and 0.899, respectively, are the top two most important subcategories for the occurrence rate. In addition, the partial contribution to the occurrence rate from the TURB subcategory is *exp*(0.498) or 1.645, from the ICE subcategory is *exp*(0.899) or 2.457, and the total adjustment term is *exp*(-11.819) or 7.363^{-6}.

Table 2- 7 Analysis of Parameter Estimates for ICAO Occurrence Categories by occurrences under Weather

Variable	Estimate of Parameter	Standard Error	Wald Chi-square	*p*-value
Intercept	-11.819	0.148	6412.79	0.0095
TURB	0.498	0.160	9.68	0.0019
ICE	0.899	0.428	4.42	0.0355

During the past twenty-six years 1985-2010, there were four occurrences under the TURB subcategory, all of them were accidents. The most serious turbulence accident was an EVA Air flight BR-2196, an A330-203 aircraft to Tokyo, Japan, happened on the March 8, 2005, which was encountered clear air turbulence (CAT) and there were 1 serious injury among 46 passengers and 10 cabin crew minor injuries. Refer to the Federal Aviation Administration (FAA) Advisory Circular 120-88A (FAA, 2006), flight attendances are asked to emphasize on personal safety when encounter turbulence and to promote communication and coordination via Crew resource management (CRM); air carriers should develop practices to improve passengers compliance with seatbelt instruction from crewmembers such as video demonstration, safety information cards and fasten seatbelt sign.

The one fatal accident occurred as classified by the ICE subcategory under the WTHR grouping category was TransAsia Airway flight GE-791 ATR-72 cargo aircraft, with 2 fatalities (including all crew) on January 22, 2003 in the southwest area of Penghu Islands, Taiwan. To prevent WTHR occurrences, it is important to have the staff of the airline personnel trained for adverse weather conditions. Hunter et al. (2011) pointed out that training and other interventions directed at reducing weather-related accidents can be described as having two general objectives: (1) to avoid entering adverse weather conditions, and (2) to survive an encounter if weather is actually penetrated.

2.3.5 Aircraft

According to the ICAO Aviation Occurrence Categories, there are three subcategories in relation to the grouping category ARCFT, which includes SCF-PP, SCF-NP, and F-NI, and the maximum likelihood method is employed to produce the estimated regression parameters associated with these subcategories. By Equation (2-3), the estimate of α is negatively significant $(\alpha = -0.478,\ p\text{ - value} < .0001)$, which means the standard errors of Poisson regression parameter estimates are under-estimated. After the under-dispersion adjustment to standard errors by SAS GENMOD DSCALE option, the results are shown in Table 2-8, where the SCF-NP is the only one significant subcategory with a *p*-value of 0.0199 associated with the regression coefficient of 1.239 and it is significantly important subcategories for evaluation of the fatality rate which means SCF-NP subcategory indicates a positive influence and it has a good explaining ability to the fatal accidents. Additionally, the partial contribution to the fatality rate by the SCF-NP subcategory is *exp*(1.239) or 3.452, and the total adjustment term is *exp*(-13.161) or 1.924^{-6}.

Table 2- 8 Analysis of Parameter Estimates for ICAO Occurrence Categories by Fatal Accidents under Aircraft

Variable	Estimate of Parameter	Standard Error	Wald Chi-square	*p*-value
Intercept	-13.161	0.284	2141.87	<.0001
SCF-NP	1.239	0.532	5.42	0.0199

This study searches the causes of System/Component Failure or Malfunction, and it is found that aircraft components are inevitably subjected to fluctuating stresses, and hence, irrespective of the mechanism of defect/crack initiation, most of these components ultimately fail as a result of fatigue fractures (Bhaumik et al., 2008).

In the past ten years from 2001 to 2010 in Taiwan, there were two occurrences of SCF-NP accidents (ASC, 2009), the most disastrous fatal accident was China Airlines flight B-747-200 B-18255 CI-611 aircraft, with 225 fatalities (including all passengers and crew) on May 25, 2002 in the northeastern area of the Penghu Islands, Taiwan. Referring to the ASC final investigation report (ASC, 2002), the in-flight breakup of the CI-611 flight was due mostly to structural failure in the aft lower lobe section of the fuselage as it approached its cruising altitude. By reviewing the B-18255 maintenance records on February 7, 1980, the aircraft suffered a tail strike occurrence at Hong Kong international airport. After the accident, the permanent repair of the tail strike was not accomplished in accordance with the Boeing Structure Repair Manual (SRM), and the repair Doubler did not extend sufficiently beyond the entire damaged area to restore the structural strength (ASC, 2002). The CI-611 case raised an important issue of the maintenance safety and risk-reduction to airlines and authorities in relation to aircraft.

2.3.6 Miscellaneous

Under the ICAO Aviation Occurrence grouping Category MISCN, the subcategories SEC, CABIN, OTHR and UNK are used as exogenous explanatory variables, among the four subcategories, the SEC and UNK shown no occurrence during study period. The maximum likelihood method is employed to produce the estimated regression parameters for CABIN and OTHR. By Equation (3), the estimate of α is slightly negatively significant $(\alpha = -0.083,\ p\text{-value} = 0.1037)$, which means the standard errors of Poisson regression parameter estimates are under-estimated. After the under-dispersion adjustment to the standard errors by SAS GENMOD DSCALE option, the results are shown in Table 2-9, where the parameter estimate is positively by significant carrying a *p*-values of 0.0002, which indicates a positive relationship of the occurrence rate with the OTHR subcategory, i.e., it has positive influence and good explaining ability to the occurrences.

Table 2- 9Analysis of Parameter Estimates for ICAO Occurrence Categories by occurrences under Miscellaneous

Variable	Estimate of Parameter	Standard Error	Wald Chi-square	*p*-value
Intercept	-11.939	0.161	5509.40	<.0001
OTHR	0.887	0.237	14.03	0.0002

This is consistent with the sequential and partial F-test by SAS GENMOD type1 and 3 options. Based on the parameter estimate in Table 8, the OTHR subcategory associated with the largest regression coefficient of 0.887 is the significantly important subcategory in relation to the occurrence rate. In addition, the partial contribution to the occurrence rate by the OTHR subcategory is *exp*(0.887) or 2.428, and the total adjustment term is *exp*(-11.939) or 6.530^{-6}.

According to the finding of the OTHR subcategory, the fatal accident was China Airlines flight CI-681 A300-600R, with one fatality (captain) on May 8, 2000, when it was on its way to Ho Chi Minh City from Taipei Chiang Kai-Shek International Airport. This kind of accident is mostly caused by the nature of pilots' work often results in work long shifts, sleep loss, sustained wakefulness, and circadian disruption associated with their schedules, which means that long-haul pilots are likely to experience elevated levels of fatigue during some flights (Petrilli et al., 2006; Samel et al., 1997a, 1997b). The CI-681 case revealed that good management on physical health of pilots and retraining of flight crew incapacity procedures are very important to aviation safety.

Chapter 3 Review of International Airports Safety Management Systems

Safety is always the highest guidance in aviation industry. In order to comply with the International Civil Aviation Organization (ICAO) requirements, any certified international airport should operate Safety Management System (SMS) from November 2005 (Federal Aviation Administration (FAA), 2007; Cardoso et al, 2008). Based on the safety goal by ICAO Safety Management Manual (SMM) (ICAO, 2009a) and Civil Aerodrome Design and Operation Standards (CAA, 2011b), the performance of Taiwan Taoyuan International Airport SMS operation was evaluated in this research.

According to the result of the research Part one, sub-category of Runway Excursion (RE) and Ground Collision (GCOL) are the top two sub-categories to affect serious incidents in Taiwan which is agreeable to the Acceptable Level of Safety (ALos) in State Safety Program (SSP) (CAA, 2011a) and Safety Management Manual (SSM). The result also can be the reference for the airport SMS operation elements and provide related information for the airport safety management operations to reach SSP Safety Targets as shown in the shaded overlapping area of Fig.1-1. Moreover, after reviewing the ICAO and other countries' SMS regulations, the research Part two develops airport SMS components and elements and evaluates performance of the Taoyuan international airport.

For the sake of understanding the management meaning and implementation for international airport safety management, this chapter introduces the definition and history for certificated airport SMS operations. The SMS history is introduced in Section 3.1; the promotion of ICAO certificated airport SMS is described in Section 3.2; the airport SMS operations implementation by England, American, Australia, and Canada is illustrated in Section 3.3 reviews on the academic research reference and methodology in aviation industries are given in Section 3.4 and 3.5. The regulation and literature reviewing are useful in developing in airport SMS research and airport safety management.

3.1 Introduction to Safety Management System

The requirement of Safety Management System (SMS) for organizations was initiated by two disasters in Europe. The Flixborough disaster occurred by Nypro Ltd caprolatam production facility explosion in 1974, and the chemical accident occurred at Flixborough blew away the village and caused 28 fatalities. The other disaster is Seveso incident in

1976, the liberated 2, 3, 7, 8-tetrachlorodibenzo-dioxin (TCDD) polluted crops, soil and animals. After the two disasters, the European Economic Community (EEC) established the directive 82/502/EEC (Seveso directive) in which article 10 is the requirement for manufacturer safety management after accidents. The Seveso article 10 mentions member States that they shall take the necessary measures when a major accident occurs, including:

a. To inform the Competent Authorities specified,

b. To provide them with the following information as soon as it becomes available:

- *the circumstances of the accident and the dangerous substances;*
- *the data available for assessing the effects of the accident on man and the environment;*
- *the emergency measures taken;*

c. To inform them of the steps envisaged:

- *to alleviate the medium and long-term effects of the accident;*
- *to prevent any recurrence of such an accident.*

In 1996, the Council of the European Union published directive 96/82/EC (Seveso Directive II) which was added to Safety Management System (SMS) in annex 3. The SMS of Seveso Directive II included:

1. ***organization and personnel** -- the roles and responsibilities of personnel involved in the management of major hazards at all levels in the organization. The identification of training needs of such personnel and the provision of the training so identified. The involvement of employees and, where appropriate, subcontractors;*
2. ***identification and evaluation of major hazards** -- adoption and implementation of procedures for systematically identifying major hazards arising from normal and abnormal operation and the assessment of their likelihood and severity;*
3. ***operational control** -- adoption and implementation of procedures and instructions for safe operation, including maintenance, of plant, processes, equipment and temporary stoppages;*
4. ***management of change** -- adoption and implementation of procedures for planning modifications to, or the design of new installations, processes or storage facilities;*
5. ***planning for emergencies** -- adoption and implementation of procedures to identify foreseeable emergencies by systematic analysis and to prepare, test and review emergency plans to respond to such emergencies;*
6. ***monitoring performance** -- adoption and implementation of procedures for the ongoing assessment of compliance with the objectives set by the operator's major accident prevention policy and safety management system, and the mechanisms*

for investigation and taking corrective action in case of non-compliance. The procedures should cover the operator's system for reporting major accidents of near misses, particularly those involving failure of protective measures, and their investigation and follow-up on the basis of lessons learnt;

7. ***audit and review*** *-- adoption and implementation of procedures for periodic systematic assessment of the major-accident prevention policy and the effectiveness and suitability of the safety management system; the documented review of performance of the policy and safety management system and its updating by senior management.*

In the mid-eighties, the most famous safety management came from Shell and DuPont companies. Shall and DuPont developed a set of 11 principles for Enhanced Safety Management (ESM) which involved having a leadership committed for safety, to having competent safety advisors, to investigating accidents etc (Hudson, 2001). ESM is not only improving the operations performance and safety but also ensure the decreasing of injuries and fatalities. Mention the SMS development for oil and gas company, Shell’s approach is based on the hazards analysis which is constrained safety goals. The Shell's Hazards and Effects Management Process (HEMP) develops four steps (Hudson, 2001):

1. Identify what hazards can be found in the operation.
2. Assess how important these hazards are.
3. Manage how the hazards to be controlled are.
4. Recover what will be done if hazards are released.

The core elements for SMS (European Process Safety Centre , 1994; Law et al., 2006) are Policy, Planning, Implementation and Performance evaluation which are developed in a successful health and safety management, HSG65 (Health and Safety Executive (HSE), 1997) by UK HSE, and its 5 elements are described below:

1. Policy- Effective health and safety policies set a clear direction for the organization to follow.
2. Organizing- An effective management structure and arrangements are in place for delivering the policy.
3. Planning- There is a planned and systematic approach to implementing the health and safety policy through an effective health and safety management system.
4. Measuring performance- Performance is measured against agreed standards to reveal when and where improvement is needed.
5. Auditing and reviewing performance- The organization learns from all relevant experience and applies the lessons.

The wide application of SMS for commercial and industrial is “Guidelines on Occupational Safety and Health Management Systems” which was formulated by the International Labor Organization (ILO) (ILO, 2001). The guidelines outline the main factors for SMS clearly and cyclically, such as policy, organization, planning and implementation, evaluation and action for improvement whose 4 elements are implemented on Guide to Occupational Health and Safety Management System, BS 8800 by British Standards Institution (BSI) in 1996 (BSI, 1996), Occupational Health and Safety Assessment Series (OHSAS) 18001, and ILO/OHS-MS by International labored Organization (ILO) (ILO, 2001). The Taiwan SMS for industrial safety operation procedure was implemented via Taiwan Occupational Safety & Health Management System (TOSHMS) in 2007, and the main task is a3-step risk management which hazard identify, risk evaluation and risk control.

3.2 Definition of ICAO SMS

Safety always is the first priority requirement for aviation industries, for this reason, ICAO defines the concept for safety in Safety Management Manuel (ICAO, 2009a) which is stated as:

“ the state in which the possibility of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and safety risk management “.

According to SMS definition for the ICAO Annex14 (ICAO, 2009b), SMS is a systematic approach to managing safety including the necessary organizational structure, accountabilities, policies and procedures. In order to reduce the aviation hazards happening and improve aviation safety quality, based on the ICAO’s Standards and Recommended Practices (SARPs), ICAO published explicit instruction for the standards for aviation industries’ SMS operations in 2005. The ICAO Annexes 1, 6, 8, 11, 13 and 14 listed the SMS operations standards to aviation service providers which included aircraft operators, approved maintenance organizations, organizations responsible for type design and/or manufacture of aircraft, air traffic service providers and certified aerodromes (ICAO, 2009a).

The SMS promoted by ICAO from 2005, and the beginning for the promotion was certified SMS operations for six aviation service providers. Until 2009, ICAO addressed the State Safety Program (SSP) and assisted member countries to establish a manner to implement a SMS for aviation service providers. Therefore, SSP is the foundation of the SMS implementation for aviation service providers (CAA, 2011a). After the SSP and

SARPs publication in 2009, the ICAO contracting states shelled refer to the SARPs and Annexes 1, 6, 8, 11, 13, and 14 to establish their SSP. The subjects for these Annexes are shown as follows (ICAO, 2009a):

- Annex 1 — Personnel Licensing,
- Annex 6 — Operation of Aircraft,
- Annex 8 — Airworthiness of Aircraft,
- Annex 11 — Air Traffic Services,
- Annex 13 — Aircraft Accident and Incident Investigation, and
- Annex 14 — Aerodromes.

The CAA of Taiwan always has responsibility to improve aviation safety quality and compliance with ICAO SARPs, even though Taiwan is not an ICAO contracting state. In this research, the focus is on the airport SMS operations, the definition of aerodrome in Annex 14 is discussed in the following. According to ICAO Annex 14 (ICAO, 2009b), an aerodrome is defined as:

A defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

For the convenience to readers, this research uses "airport" to replace "aerodrome" in Section 3.2 and the following Section for empirical study. Based on the airport certification process in Annex 14, an aerodrome manual shall include all pertinent information on the aerodrome site, facilities, services, equipment, operating procedures, organization and management shall include a SMS which is submitted by the applicant for approval/acceptance prior to granting the aerodrome certificate. Therefore, airport SMS is important and necessary for the certification and operation reasons. The SMS operating standards of certificated aerodromes for ICAO contracting state are also published in Annex 14 - Aerodrome Design and Operations (ICAO, 2009b). The details for certificated aerodromes SMS requirements are shown below:

States shall require, as part of their State safety program, that a certified aerodrome implement a safety management system acceptable to the State that, as a minimum:

1. *identifies safety hazards;*
2. *ensures the implementation of remedial action necessary to maintain agreed safety performance;*
3. *provides for continuous monitoring and regular assessment of the safety performance; and*
4. *aims at a continuous improvement of the overall performance of the safety management system.*

An airport SMS is a management system for the safety management by airport organizations. In accordance with ICAO SMM (ICAO, 2009a), Annex 14 (ICAO, 2009b) and Civil Aerodrome Design and Operation Standards (CAA, 2011b) (see Table 3-1), the airport SMS framework includes four components and twelve elements which expressed the minimum requirements of SMS implementation. The implementation of SMS framework shall correspond with the size of airport organization and the complexity of airport service provider. The details of SMS framework are listed in Appendix 2 of this thesis, and the brief is outlined below:

1. *Safety policy and objectives*

    1.1 Management commitment and responsibility

    1.2 Safety accountabilities

    1.3 Appointment of key safety personnel

    1.4 Coordination of emergency response planning

    1.5 SMS documentation

2. Safety risk management

    2.1 Hazard identification

    2.2 Safety risk assessment and mitigation

3. Safety assurance

    3.1 Safety performance monitoring and measurement

    3.2 The management of change

    3.3 Continuous improvement of the SMS

4. Safety promotion

    4.1 Training and education

    4.2 Safety communication

Table 3- 1 ICAO airport SMS documents collection

ICAO documents	Version/Date	Chapter/ Name
Doc 9859 AN/474 Safety Management Manual (SMM)	2nd Edition/ Jul. 2009	Chapter 6/ ICAO Safety Management SARPs
		Chapter 8/ SMS Planning The ICAO SMS Frame work
Annex 14 Vol.1 Aerodrome Design and Operation	5th Edition/ Jul. 2009	Chapter 1/ 1.5 Safety Management
Doc 9774 AN/969 Manual on Certification of Aerodromes	1st Edition/ Jan. 2001	Chapter 3/ 3A.2.1 Definition Safety Management System

Source: ICAO (2001b; 2009a; 2009b)

3.3 International Airport SMS Implementation Overview

In 2009, ICAO published the SARs (Standards and Recommended Practices, SARs) for SSP (State Safety Program, SSP) stating that the contracting states shall establish their SSP. Contrast to Taiwan completed the first edition of State Safety Program (CAA, 2011a) and complied with the ICAO Annex 14 requirement for airport SMS implementation. Taiwan Civil Aeronautics Administration (CAA) not only described the SMS framework in Civil Aerodrome Design and Operation Standards Appendix 7 (CAA, 2011b) but also complied with the ICAO SMM requirements of establishing airport SMS for aerodrome certificate continually. Until now, Taipei Shongshan, Taoyuan and Kaohsiung international airports have completed the airport SMS manual establishing in Taiwan.

In order to improve airport safety, ICAO published and implemented the airport SMS in November 2005, and the initiative state agencies includes Civil Aviation Safety Authority (CASA) in Australia, Federal Aviation Administration (FAA)/ Airport Council Research Program (ACRP)/ Transportation Research Board (TRB) in the United States, Transport Canada, United Kingdom Civil Aviation Authority (UK CAA) (Cardoso et al., 2008). These countries use ICAO airport SMS requirements as the main framework to establish their airport SMS documents. This study briefs the airport SMS documents by the four states mentioned above as following paragraphs and summaries the information for airport SMS documents in Table 3-2 and Appendix 3.

1. The United Kingdom

UK CAA formulated airport SMS documents which included CAP728 and CAP 168. The CAP728 (UK CAA, 2003) is SMS guidance to airport and air traffic service on development of SMS and the certified airport SMS requirements are addressed in CAP128 Appendix 2C (UK CAA, 2011). In Safety accountability component of CAP128, UK CAA asks the aerodrome Accountable Manager to ensure that all airport activities can be financed and carry out the standard. UK CAA pointed out the financial factor which is the most important for airport SMS implementation. According to CAP128 Appendix 2C, the airport SMS framework is divided into four components and twelve elements which are described in Table 3-2 and Appendix 3.

2. Australia

Australia Civil Aviation Safety Authority (CASA) published the Advisory Circular (AC)-139-16(0) (CASA, 2005) to assist airport in establishing a SMS for aerodrome. In this AC, CASA focus on human and organization aspects of operation and emphasizes that airport SMS is not “one size fit all”. The AC concentrates on an eight-step process as it relates to the operation of airport, and the eight step process is shown in Table 3-2 and Appendix 3.

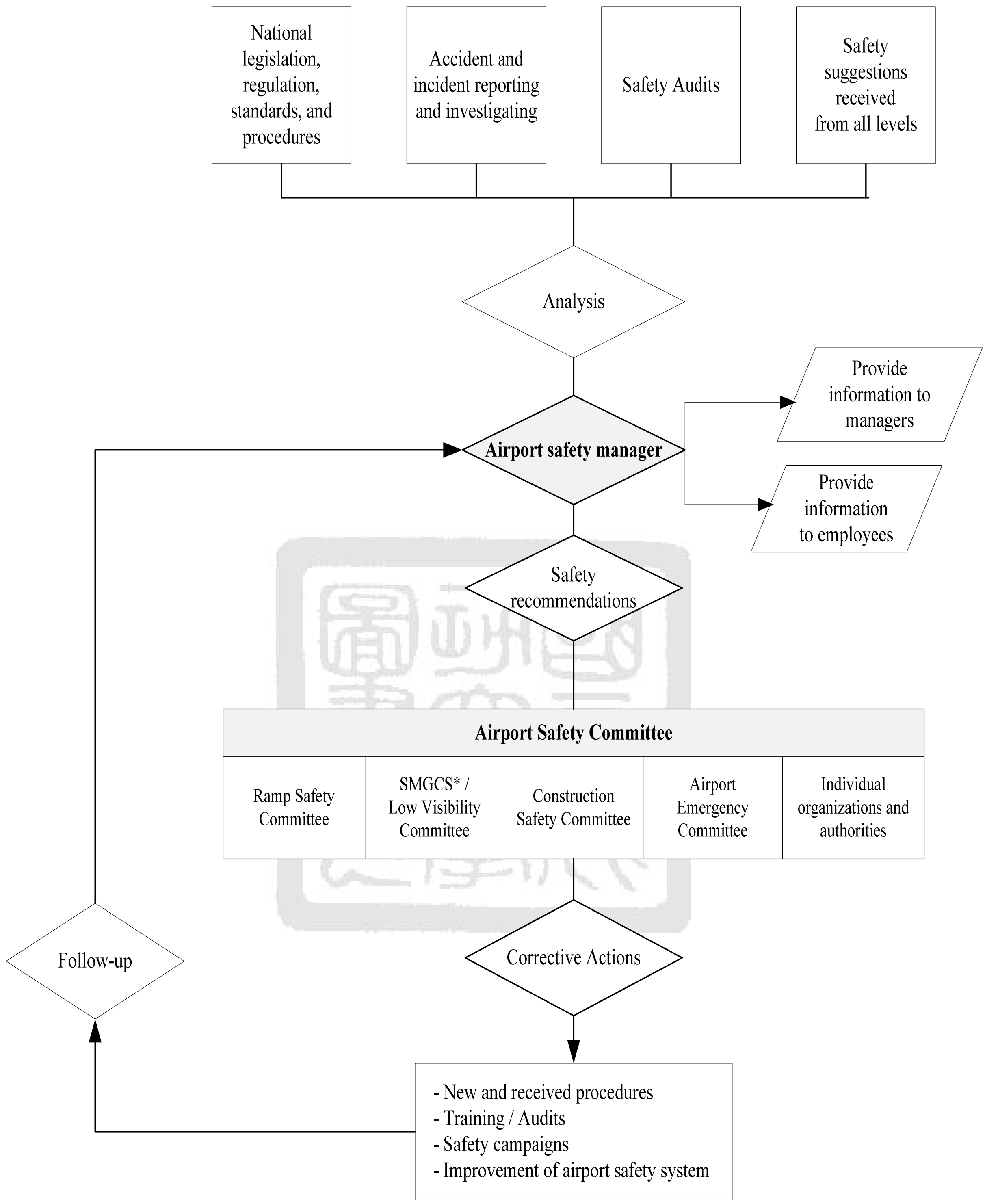
3. The United States

The AC 150/5200-37 (FAA, 2007) was published by the Federal Aviation Administration (FAA) of the United States (US) of Department of Transportation in 2007. To be consistent with ICAO SARPs requirements for certified aerodrome SMS, FAA established safety regulations in 14 CFR Part 139 (14 CFR Part 139) to be the regulation for five hundred seventy airports certification in the United States. In this AC, the character of SMS is a feedback stilly for lifecycle via safety information flow and shown as Fig. 3-1.

Regarding AC150/5200-37, FAA emphasizes two categories for safety culture and Safety Risk Management (SRM). Safety culture is both attitudinal and structural; it relates to individuals and organizations and consists of the safety perceive and appropriate action. For this reason, safety culture is very difficult to measure. To mention SRM, it is both heart and fundamental which is the core of SMS. Through the SRM process, the airport organization identifies hazards and feedback appropriated risk mitigation strategies. In order to understand the components of airport SMS in AC 150/5200-37, the definition of components are described in Table 3-2 and Appendix 3.

4. Canada

The AC300-002 (TCCA, 2009) for Safety Management System Implementation Procedures for Airport Operators was published by Transport Canada Civil Aviation (TCCA). TCCA considered that safety management involves organizational as well as culture change; for this reason, the AC300-002 was divided to four phases for implementation for airport SMS. During phase 1, the certified holder shall comply with document, gap analysis, project plan, the components of Safety management plan, Documents management, Safety oversight and Training have to establish during phase 2. In order to meet the requirement in phase 2, three elements of Safety oversight are demonstrated to TCCA during phase 3, and these elements are appeared in Table 3-2 and Appendix 3.



* Surface Movement Guidance and Control System

Fig. 3- 1 SMS lifecycle overview

Source: AC 150/5200-37 (FAA, 2007)

Table 3- 2 Airport SMS components and elements for requirements

ICAO **Annex14 (2009b)**	**UK CAA** **CAP 168 (UK CAA, 2011)**	**Australia CASA** **AC 139-016 (CASA, 2005)**	**U.S. FAA** **AC 150/5200-37 (FAA, 2007)**	**Canada TCCA** **AC 300-002 (TCCA, 2009)**
1. Safety policy and objectives - Management commitment and responsibility - Safety accountabilities - Appointment of key safety person - Coordination of emergency response planning - SMS documentation 2. Safety risk management - Hazard identification - Safety risk assessment and mitigation 3. Safety assurance - Safety performance monitoring and measurement - The management of change - Continuous improvement of SMS 4. Safety promotion - Training and education - Safety communication	1. Safety policy and objectives - Management commitment and responsibility - Safety accountability - Appointment of key personnel - Coordination of emergency response planning - SMS documentation 2. Safety Risk Management - Hazard identification - Safety risk assessment and mitigation 3. Safety Assurance - Safety performance monitoring and measurement - Management of change - Continuous improvement of the SMS 4. Safety Promotion - Training and education - Safety communication	An eight-step process as it relates to the operation of an aerodrome. 1. Policy 2. Management accountability 3. Establishing a process to manage risks 4. Setting up a reporting system to record hazards, risks and actions taken 5. Training and educating staff 6. Auditing the operation and investigating incidents and accidents 7. Setting up a system to control documentation and data. 8. Evaluating how the system is operating.	1. Safety Policy and Objectives - Safety Policy - Safety objectives 2. Safety Risk Management 3. Safety Assurance 4. Safety Promotion. - Safety promotion - Safety training and education	1. Safety management plan - Safety policy - Non-punitive reporting policy - Roles, responsibilities and employee involvement - Communication - Safety planning, objectives and goals - Performance measurement - Management review 2. Document management - Identification and maintenance of applicable regulations - SMS documentation - Records management 3. Safety oversight - Reactive processes - Proactive processes - Investigation and analysis - Risk management 4. Training - Training, awareness and competence 5. Quality assurance - Quality assurance 6. Emergency preparedness - Emergency preparedness and response

3.4 SMS Literature reviewing

In November 2005, ICAO asked the contracting States to comply with the SMS requirements of SARPs and Annex 14 (ICAO, 2009b) for certified airport issue. Since airport SMS is a recently developed safety management concept, and the direct literatures are limited (Cardoso et al., 2008). For this reason, this study extends literature searching for aviation industries SMS and aviation industries safety performance evaluation. The aviation industries SMS literature reviewing has helped this study establish the airport SMS performance evaluation indicators and find the appropriate methodologies for an empirical study. Besides, the literatures of methodologies will also be discussed in the third part.

A. The aviation industries SMS literatures:

In Aviation Industries SMS literatures, McDonald et al. (2000) researched on the safety culture, safety climate and SMS subjects for the four aircraft maintenance organizations. The participated included Chief Executives, production and middle management, quality management, quality investigators/auditors and training personnel. The research pointed out the measures of compliance with task procedures and safety attitudes to check if they are the same between four organizations, and the different occupation groups have different safety attitudes and safety climate. McDonald et al. (2000) analyzed the natures of different maintenance organization SMS, and referred to regulations of the European Joint Aviation Authorities governing maintenance organizations (JAR 145), they established a revised SMS model (see Fig. 3-2). The elements of a revised SMS model are described below:

1. Safety policy - how safety is represented as an organizational goal and the organization’s strategy for achieving its safety goals.
2. Safety standards - the global criteria against which the organization judges its level of safety.
3. Planning and organization of work - the management activities to ensure the provision of resources in the areas of methods/documentation, personnel, parts and facilities, in order to carry out the organization’s functions.
4. Normal operational practice - the normal practice or behavior in carrying out the organization’s functions.
5. Monitoring - all the activities of monitoring and review of operations, including auditing, incident investigation, quality reporting, etc.
6. Feedback - transfer of information of the various monitoring functions to potential users at all levels of the system.

7. Change - the use of information in effecting change for the elements in the system, particularly in change of the human and organizational aspects and in responds by information that these two aspects of the system are not functioning optimally.

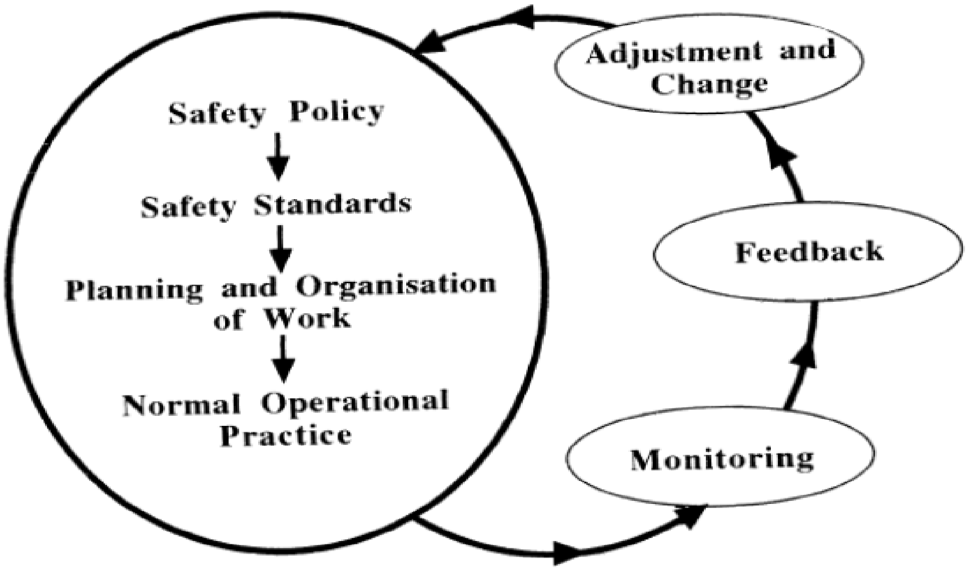


Fig. 3- 2 Revised SMS model

Source: McDonald et al. (2000)

The revised SMS model (McDonald et al., 2000) are emphasized the implementations for the elements of Safety Policy, Safety Standards, Planning and Organization of work and Normal Operational Practice which are affected by the elements of Monitoring, Feedback and Adjustment and Change in organization. In other words, the information of implementation SMS system should feed to organizational activities which effect change in system. The revised SMS model not only point out the nature of sequence and cycle for elements, but also illustrates the co-ordination between the different elements in organization. Due to the above natures of SMS elements, recent researches focus on the relatedness and important ranking for SMS elements.

After ICAO SARPs and SMS were published in 2005, the academic researches tend to discuss the influence and importance of SMS components and elements for airlines. Hsu (2008) employed the concept of proactive safety for airline SMS to discover the critical organization factors which affect the proactive safety on crew via the Flight Management Attitudes Questionnaire (FMAQ). The critical organizational factors include: Crew safety compliance and participation, Managerial decision, Operational system, Communication and Management leadership and commitment.

Liou et al. (2008) built airline SMS factors (see Table 3-3) via regulations reviewing (such as: US AC120-92, UK CAP712, and Taiwan CAA AC-120-32A). The Delphi method was used to collect the experts' advices and to develop the SMS factors, and then the relationships between SMS factors were uncovered via fuzzy Decision Making Trial Evaluation Laboratory (DEMATEL) method. By the Impact-relations map (IRM) of DEMATEL, the safety triangle shape was determined by SMS factors related degree. Liou et al. (2008) pointed out that "Strategy and policy" group of SMS factors was the top of safety triangle in IRM and the most important role in the SMS.

Table 3- 3 The Groups and factors for airline SMS

Group	Factors
Strategy and policy group	Safety policy Safety rules and regulations Safety Committee
Implementation group	Documentation Equipments Work practice
Human factor group	Communication Safety culture Training and competency
Monitoring and feedback group	Incident investigation and analysis Safety risk management

Source: Liou et al. (2008)

Hsu et al. (2010) built a critical airline SMS framework (see Table 3-4), and probe the relations and importance for SMS components and elements via a hybrid model by the method of Gray Relational Analysis (GRA), Decision Making Trial Evaluation Laboratory (DEMATEL) and ANP. The airline SMS framework was extracted from regulations and experts' advices via 0.75 threshold value of GRA. The results of ANP for weights ranking of the top five components were Safety policy, Safety culture, Communication, Training-awareness and competence, Identification and maintenance of applicable regulations. Hsu also argued that "Safety policy" and "Safety objective and goals" were airlines safety targets for airline' business core function and a minimum accepted safety level to authority. Besides, "Organization" dimension has the highest positive impact level in impacted-direction map (IMP), which is the largest net generator of effects and plays the most important roles in an airline SMS.

Table 3- 4 Critical airlines SMS framework

Dimensions	Components
Organization	Safety policy
	Safety objective and goals
	Organizational structure, accountability and responsibility
	Management commitment
	Performance measurement/baseline
Documentation	Identification and maintenance of applicable regulations
Risk Management	Hazard identification
	Safety analysis capability
	Risk assessment
	Recommending action based on safety evaluation
Safety Promotion	Training- awareness and competence
	Safety culture
	Communication

Source: Hsu et al. (2010)

B. Aviation industries safety performance evaluation

Chang and Yeh (2004) presented the airline safety index (see Table 3-5) which was based on proactive safety measure and developed via literatures generalization. The method of Analytic Hierarchy Process (AHP) was used to obtain the weights of safety index and the hierarchy framework for safety level. Because the attributes of some safety indexes were qualitative and conflicting, the multi-attribute decision making (MADM) method was used. Due to this reason, Chang and Yeh (2004) employed fuzzy MADM method to evaluate airline safety performance via fuzzy linguistic measure by experts. In order to avoid the unreliable process of comparing fuzzy number, and a general concept of MADM realized via the best alternative should have the shortest distance from positive ideal solution (PIS) and the longest distance from have the negative ideal solution (NIS).

Table 3- 5 Taiwan's major airlines safety level for evaluation

Dimension	Safety measure	Safety evaluation
Management	Safety policy and strategy	fuzzy assessment via surveys
	Management attitude/commitment	fuzzy assessment via surveys
	Employee attitude/commitment	fuzzy assessment via surveys
	Safety personnel rate	total number of flights/total number of safety personnel
Operations	Competence status of flight crew	fuzzy assessment via surveys
	Compliance with aviation task procedures	fuzzy assessment via surveys
	Training status of pilots	average training activities per pilot
	Incident and accident rate	number of accidents per 100,000 departures
Maintenance	Compliance with maintenance task procedures	fuzzy assessment via surveys
	Training status of personnel	average training activities per worker
	Crew competence rate	total number of certificated technicians/total number of maintenance crew
Planning	Average age of fleet	years
	Aircraft types	number

Source: Chang and Yeh (2004)

In order to reflect the relationships and degree of dependence between airline safety factors, Liou et al. (2007) used a hybrid model for DEMATEL and an ANP method to illustrate the inter-dependence and feedback of safety factors. The airline safety measurements were established by experts’ consultation and regulation reference which include four dimensions and eleven criterions (see as Table. 3-6). The airlines safety measurements’ weights and importance were produced via ANP, and airlines safety performance values were obtained by Weighted Sum Method (WSM).

Table 3- 6 The measurements for airline safety system

Dimensions	Components
Management	Safety policy and strategy of airlines
	Manager' attitude/commitment
	Employee attitude/commitment
Operations	Competence status of flight crew
	Compliance with aviation task procedures
	Training status of pilots
Maintenance	Compliance with maintenance task procedures
	Training status of maintenance personnel
	Number of certificated technicians/ number of maintenance crew
Accident rate	Number of accidents per 100,000 departures

Source: Liou et al. (2007)

Regarding airport SMS performance evaluation literatures, Cardoso et al. (2008) described that airport SMS performance monitoring is not only base on number of accidents and loss of life, but also considers the latent conditions and near-miss evens for airport SMS. In order to evaluate airport airside SMS operations, Cardoso et al. (2008) used the airside Individual Performance Indicators (IPIs) (see Table 3-7) and Overall Performance Indicators (OPIs) for airport SMS. The IPIs was developed and validated by airport operators in South America according to ten priority groups. Cardoso et al. (2008) focused on the ramp accidents for airport SMS performance evaluation and refer to the natures of IPIs which are listed below:

- Able to reflect a link between a latent condition and possible outcomes/accidents;
- Easy to be quantified;
- Not subjective;
- Consistent across time;
- Possibility to be combined with other IPIs to obtain Overall Performance Indicators (OPIs);

Cardoso et al. (2008) used group decision method to gain the priority and weights for IPIs groups (see as Table 3-7). This study assumed that the IPIs should be limited to one-year period, but averaged or estimated for 10,000 aircraft operations and depend on the airport size. Weighted Sum Method (WSM) was employed by IPIs, where IPIs multiply the weights to gain OPI value.

Table 3- 7 The IPIs of airport SMS for respective priority groups and weights

Group/Priority	**Individual Performance Indicators for Airports SMS**	**Weights**
1	Runway incursions Aircraft bird/wildlife strikes Incidents on each runway Foreign Object Damage/Foreign Object Debris (FOD)	10
2	FOD found on each runway Incidents on each apron Incidents on each taxiway	9
3	Reports on slippery runway	8
4	FOD found on each taxiway FOD found on each apron	7
5	Air navigation aids equipments out of service Non authorized vehicles on each runway Driver infractions on each runway Infractions during aircraft refueling on each apron	6
6	Obstacles that do not comply with standards Reports on surface distresses on each runway Lights that do not comply with standards Non authorized persons on each runway Markings that do not comply with standards Signs that do not comply with standards	5
7	Reports on the presence of birds/wildlife	
8	Failures observed during a full-scale aerodrome emergency drill Non authorized vehicles on each taxiway Non authorized vehicles on each apron Driver infractions on each apron	3
9	Non authorized persons on each taxiway Non authorized persons on each apron Driver infractions on each taxiway	2
10	Reports on surface distresses on each taxiway Reports on surface distresses on each apron	1

Source: Cardoso et al. (2008)

C. Methodology literature reviewing

By reviewing the aviation industries SMS and safety assessment literatures, one finds that most researchers used the method of Multiple Criteria Decision Making (MCDM) to develop the safety dimensions and safety criterion (Chang and Yeh, 2004; Liou et al., 2007; Liou et al., 2008; Cardoso et al., 2008; Hsu et al., 2010). The natures of MCDM method are listed as follows (Pohekar and Ramachandran, 2004):

1. MCDM method to deal with the process of making decision for multiple objectives.
2. The quantifiable or non-quantifiable and multiple criterions to be chosen by decision makers.
3. Solution of MCDM problems is usually compromise and preferences for decision makers under the objectives conflicting situations.

The MCDM method is further taught in the multi-objective decision making (MODM) and the muti-attribute decision making (MADM) classes. MODM is mainly to assess objectives and to find the optimal solution under the limited resources (Yoon and Hwang, 1985). In MADM, decision makers based on the properties of a problem to evaluate a small number of alternatives and to obtain the ideal solution via comparison with the attribute of alternatives (Pohekar and Ramachandran, 2004) and MADM method is often to solve various decision and/or selection problems (Mahdavi et al., 2008). Chen and Klein (1997) pointed out that fuzzy MADM was developed due to the lack of perception in assessing the relative importance of alternatives and the performance ratings of alternatives with respect to an attribute. Since the fuzzy MADM sources have the natures of imprecision natures such as: (1) unquantifiable information, (2) incomplete information, (3) non-obtainable information, and (4) partial ignorance (Chen and Hwang, 1992), the fuzzy MADM methods are used to evaluate airport SMS performance according to the attribute of research objectives for Part two.

In the aviation safety field, recent researchers studied the relationship and affections between safety factors/ indexes/criterions (McDonald et al., 2000; Liou et al., 2007; Liou et al., 2008; Hsu et al., 2010) and to consider the natures of dependence and feedback among criterion and alternatives of problems, an ANP method was developed by Saaty (1996). Based on the literature reviewing and experts advices, this study uses analytic network process (ANP) to produce airport SMS components and elements weights and importance.

In order to investigate the characters of decision making problem in real life, fuzzy MADM method is implemented to evaluate the ratings and weights of criterion for imprecision, subjective and ambiguous via linguistic variables and fuzzy numbers (Zadeh, 1965; Bellman and Zadeh, 1970; Zimmermann, 1991; Zimmermann, 1996). FMADM methods are wildly applied to solve aviation industry on decision making problems (Borenstein and Zimmerman, 1988; Chang and Yeh, 2002, 2004; Wang and Chang, 2007; Chou et al., 2011; Torlak et al., 2011). This study intends to illustrate the real airport SMS and then to choose a common fuzzy MADM method for fuzzy technique for ordering preference by similarity to ideal solution (TOPSIS) to evaluate the airport SMS performance. The idea of the fuzzy TOPSIS is that the chosen alternative has the shortest distance from the fuzzy positive ideal solution (FPIS) and it has the farthest distance to the fuzzy negative ideal solution (Awasthi and Chauhan, 2012).

3.5 Summary

The concept of Safety Management System (SMS) was originated in reducing safety accidents of petrochemistry industries in the 1970s. ILO established five main factors for SMS which are Policy, Organization, Planning and Implementation, Evaluation and Action for Improvement. The ILO's SMS factors' feedback and cycle natures reduce risks and hazards in system (ILO, 2001).

This study refers to Civil Aerodrome Design and Operation Standards (CAA, 2011b), ICAO Annex 14 (ICAO, 2009b) and compares to airport SMS regulations for the UK, Australia, the United States and Canada, then generates the Taiwan airport SMS components for evaluation performance, which consist of Safety policy and objectives, Safety risk management, Safety assurance and Safety promotion. The definitions of the airport SMS for components and elements are described in Section 3.2.2. Reviewing the SMS academic research in aviation industries, there are characters of order and cycle natures between the SMS components and elements (McDonald et al., 2000). In aviation industry operation systems, the SMS components and elements are related by each other and behave some hierarchy natures (Liou and Yen, 2008; Hsu, 2010). Regarding aviation industries safety performance evaluation research, group decision making methods are used to evaluate safety items' importance and weights, such as Analytic Hierarchy Process (AHP) method (Chang and Yeh, 2004), ANP method (Hsu et al., 2010), and WSM method (Cardoso et al., 2008). Liou et al. (2007) considered the interactions between safety evaluation items and Hsu et al. (2010) proved the interactions between SMS components and elements via DEMETEL and ANP methods.

Research in Part two focuses on the airport SMS components and elements developing and framework establishing for performance evaluation. Thus, in the first stage of this research, this study intends to review the ICAO and other countries' airport SMS regulations and to build the airport SMS hierarchy framework and then to obtain the weights and importance of airport SMS components and elements via expert opinions by ANP method. Based on the attributes of airport SMS which agree to the conditions of MADM method, this study uses fuzzy TOPSIS method to evaluate safety performance for Taiwanese Taoyuan, Kaohsiung and Taipei Songshang international airport SMS operations in the second stage.

Chapter 4 Performance on Airport SMS

In the Part two research, components and elements employed in the performance evaluation on an airport SMS are established by reviewing the ICAO, Taiwan CAA, and United States FAA certificated airport regulations. Due to the characters of imprecision on airport SMS components and elements such as unquantifiable, incomplete information (Chen and Klein, 1997), their qualitative measures are employed following the multi-attributes under uncertainty. Therefore, according to the nature of airport SMS operations and performance evaluation, this study intends to solve a MADM (Multi-attribute decision making) problem.

There are two stages of research process as described below:

- The first stage:

  Based on the characters of airport SMS for hierarchy, feedback and inner loop, this research uses the Analytic Network Process (ANP) to gain the weights of airport SMS components and elements at this stage. The performance evaluations of components and elements on an airport SMS are developed via literature reviewing. Their weights and importance are obtained by experts' subjective assessment via ANP method.
- The second stage:

  Due to the lack of perception in assessing the relative importance of alternatives and the performance ratings of alternatives with respect to an attribute (Chen and Klein, 1997), this research choose the popular fuzzy MADM method (Zhang, 2004) for fuzzy Technique of Ordering Preference by Similarity to Ideal Solution (fuzzy TOPSIS) to evaluate the airport SMS performance for three international airports in Taiwan (Taoyuan, Kaohsiung and Taipei Songshang). Comparisons of three airports SMS performance evaluations are made by this part of research.

4.1 Performance by Analytic Network Process

The Analytic Hierarchy Process (AHP) was proposed by Saaty in 1971, which was used to solve MADM problems and to describe the relationship between components and elements via linear hierarchy structure. The components and elements of AHP are independent and they have a linear top-to-bottom structure (see AHP in Fig. 4-1). In other words, the top level is a goal and the lower levels are criteria, sub-criteria and alternative in AHP linear structure (Saaty, 1999; Saaty and Vargas, 2006). The weights of the components and elements are obtained by calculating by pair-wise comparison matrix similar to AHP method.

In real life, the components and elements of a real problem in its nature are of dependence, interaction and feedback relations, thus, the Analytic Network Process (ANP) was first introduced by Saaty in 1980 (Saaty, 2008). The ANP structure looks like networks with nonlinear nature in which the components and elements of connections are dependent (see ANP in Fig. 4-1). The weights and priorities of the components and elements are derived by using pairwise comparison matrices which come as parts of the columns in a supermatrix.

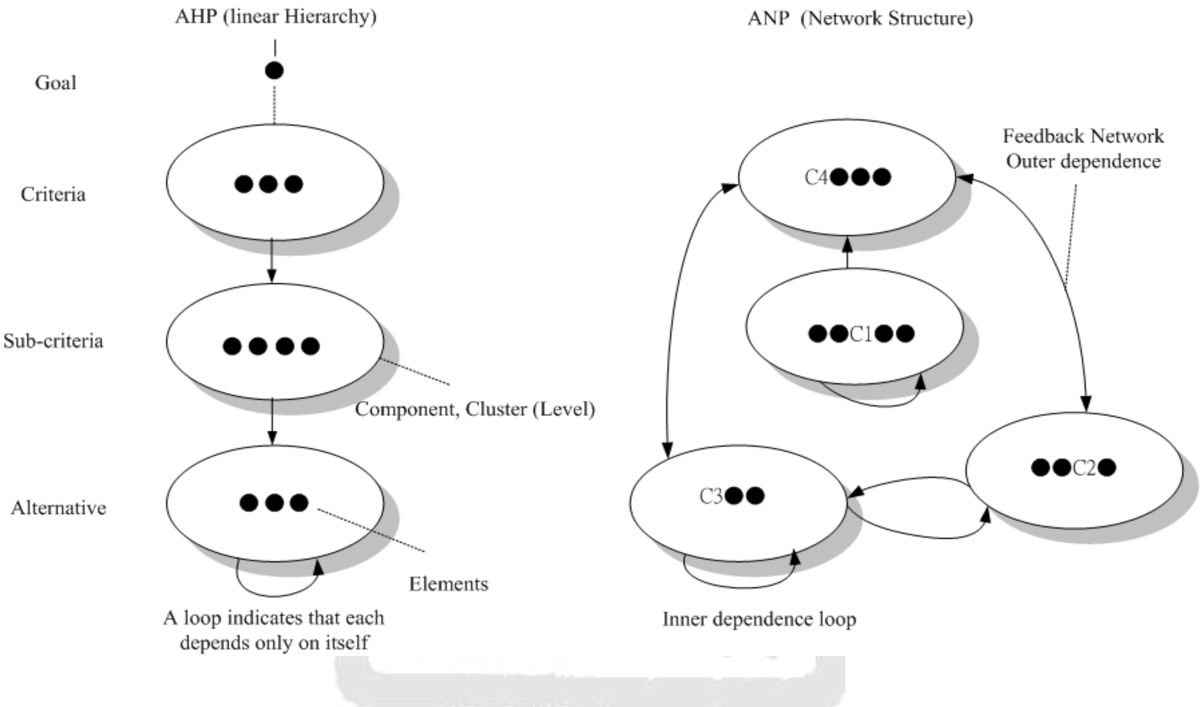


Fig. 4- 1 Structural differences between AHP (left) and ANP (right)
Source: Saaty and Vargas (2006)

Refer to the right side of Fig. 4-1, the components of ANP have both liner and outer dependence among elements. Arc from components *C*4 to C2, C4 to C3 and C2 to C3 exhibits the outer dependence property. Loops in the components C1 and C3 demonstrate inner dependence property among elements. The verbal judgment scale of an ANP is divided into five levels to reflect the relative importance (see Table 4-1). The Consistency Index (C.I.) of a comparison matrix is given by $C.I. = (\lambda_{\max} - n)/(n-1)$, where $\lambda_{\max}$ is the maximum eigenvalue of a comparison matrix, and n is the order of the matrix. The Consistency Ratio (C.R.) is defined by dividing the ratio by a corresponding one of the following set of numbers shown in Table 4-2, each of which is an average random consistency index calculated with very large number of samples (Saaty and Vargas, 2006).

Table 4- 1 Fundamental Scale of ANP

Verbal judgment	Numerical values
Equal importance	1
Moderate importance of one over another	3
Strong or essential importance	5
Very strong or demonstrated importance	7
Extreme importance	9
Intermediate values	2,4,6,8
Use reciprocals for inverse comparisons	

Source: Saaty and Vargas (2006)

Table 4- 2 Random Index

Order	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: Saaty (1980)

The ANP can be illustrated by the following steps (Azimi et al., 2011):

Step 1: To decompose the problem as a model structure:

Based on literatures, expert's knowledge and the nature of a problem, the problem is decomposed to a goal, components and elements to form a model. The weights are produced by all *n* components C_n's regarding the dependencies in relevance to an overall criterion through expert's investigation.

Step 2: Pair-wise comparison matrices:

According to the model structure, each component and element are compared with each other to obtain the relative importance to form Pair-wise comparison matrices. The relative importance values are determined by using the Saaty's 1-9 scale (Table 4-1) (Saaty and Vargas, 2006). The relative importance of group judgments are aggregated by geometric mean (Saaty, 2008) before the pair-wise comparison matrices can be established.

Step 3: Supermatrix formation:

At this stage, the limiting priorities of the influence from the supermatrix are constructed. In order to obtain the priorities, each column sum of the supermatrix must be transformed to unity which simply makes it into a stochastic matrix (Saaty and Vargas, 2006). The concept of a supermatrix is similar to a Markov chain process in which Saaty has developed it to synthesize ratio scales for ANP (Saaty, 1996). Let the components of a decision system be $C_1, C_2 \ldots, C_n$, and let the lth component have p_l elements, $l = 1, 2, \ldots, n$, denoted by $e_{l1}, e_{l2}, \ldots, e_{lp_l}$. The influence of a set of elements under a component, on any element from another component, can be represented by a priority vector (called eigenvector) by applying pair-wise comparison technique. These priority vectors are grouped and located in appropriate positions in a supermatrix based on the flow of influence from one component to another component, or from one component to itself as in the loop. A standard form of a supermatrix used in this study is given as in Fig. 4-2, where W_{ij} is a sub-matrix of principal eigenvectors of the influence of the elements in the *i*th component (C_i) connected to the *j*th component (C_j). For example, in Fig. 4-2, W_{11} represents the sub-matrix with p_1 elements under component 1 (C_1) as denoted by $e_{11}, e_{12}, \ldots, e_{1p_1}$ which are located under C_1 and to the left side of the supermaix. If the *i*th component has no influence or no correlation with the *j*th component, then the sub-matrix $W_{ij} = 0$, where 0 is a zero matrix. The form of the supermatrix depends on the nature of its structure. The sub-matrix W_{ij}, $(i \neq j)$, is multiplied by the weight C_{ij} of the influence from component C_i to component C_j, where $(C_{i1}, C_{i2}, C_{i3}, C_{i4})$ is the principal eigenvector (weights) of the comparison matrix formed with C_i as a leading component relative to all others. Note that, in this study, all columns in W_{ij} have the same principal eigenvectors. The sub-matrix W_{ii} stands for the feedback matrix within the *i*th component. In this way, the elements in each column of the supermatrix are weighted and they are summed to one. The weighted supermatrix should be raised to the power of 2k+1 (k is any arbitrarily large number) in order to have the weights converged (Saaty 1996), because raising exponential powers to the supermatrix give stable relative influences of the elements on each other, *i.e.*, take a limiting value on W, that is, $\lim_{k \to \infty} W^{2k+1}$, to obtain the long-term relative weights (Saaty, 1996).

Step 4. Selection of the important elements or components:

If a supermatrix only includes components that are interrelated, additional calculations must be made to obtain the overall priorities. The element or component with the largest weight should be selected, as it is the important element or component as determined by the calculations of supermatrix.

$$W = \begin{array}{cc} & \begin{array}{cccc} \overset{C_1}{e_{11}\ e_{12}\cdots\ e_{1p_1}} & \overset{C_2}{e_{21}\ e_{22}\cdots\ e_{2p_2}\cdots} & \cdots & \overset{C_n}{e_{n1}\ e_{n2}\cdots\ e_{np_n}} \end{array} \\ \begin{array}{c} C_1 \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1p_1} \end{array} \\ C_2 \begin{array}{c} e_{21} \\ e_{22} \\ \vdots \\ e_{2p_2} \end{array} \\ \vdots \\ C_n \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{np_n} \end{array} \end{array} & \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & W_{22} & \cdots & W_{2n} \\ \vdots & \vdots & & \vdots \\ W_{n1} & W_{n2} & \cdots & W_{nn} \end{bmatrix} \end{array}$$

Fig. 4- 2 Supermatrix

4.2 Establishment of airport SMS components and elements

As this study mentions in sections 3.2 and 3.3, the ICAO airport SMS is a requirements for certificated aerodrome, this study is referred to the regulations for airport SMS and develops four components and twelve elements for the airport SMS performance evaluation. The regulations of airport SMS are based on the ICAO SMM (ICAO, 2009b), Civil Aerodrome Design and Operation Standards: Appendix 7 Framework for SMS (CAA, 2011b), FAA AC 150/5200-37 (FAA, 2007) and Airport Cooperative Research Program (ACRP) report 1: Safety Management System for Airports (TRB, 2007). The descriptions and SMS structure of components and elements are described as bellow and summarized in Table 4-2 and Figure 4-4.

$\boldsymbol{C_1}$ **Safety policy and objectives** (ICAO, 2009b)

Safety policy of airport shall reflect organizational commitments regarding safety. Safety policy shall include: the necessary resources for implementation safety policy, safety reporting procedure and safety organization structure. Safety objectives completed by four elements are illustrated as follows:

- $\boldsymbol{e_{11}}$ Management commitment and responsibility)(ICAO, 2009b),
- $\boldsymbol{e_{12}}$ Safety accountabilities (ICAO, 2009b),
- $\boldsymbol{e_{13}}$ Appointment of key safety personnel (ICAO, 2009b),
- $\boldsymbol{e_{14}}$ Coordination of emergency response planning (ICAO, 2009b), and
- $\boldsymbol{e_{15}}$ SMS documentation (ICAO, 2009b).

***C_2* Safety risk management, SRM** (ICAO, 2009b)

Safely risk management (SRM) is the fundamental component of SMS (FAA, 2007). Based on the process of hazard identification, risk assessment, risk mitigation and tracking, SMS reduces risks to the acceptable level. Under SRM component, the predictive risk matrix is used to assess, track and monitor risks continually until the risk level is acceptable. SRM component contains the following four elements:

- e_{21} Hazard identification (ICAO, 2009) (FAA, 2007),
- e_{22} Safety risk assessment system (ICAO, 2009b) (FAA, 2007),
- e_{23} Safety risk mitigation strategies (FAA, 2007), and
- e_{24} To implement, tracks and monitor the mitigation (FAA, 2007).

***C_3* Safety assurance** (ICAO, 2009b)

Safety auditing is the core safety management activity. The component of Safety assurance implements internal audits, external audits and safety oversight, thus products feedback on the safety performance of organization (FAA, 2007). Safety performance monitoring not only validates airport SMS, but also confirm the safety objectives of organization. Airport safety performance improves continually through regular safety review and evaluation of the following four elements under safety assurance:

- e_{31} Safety performance monitoring and measurement (ICAO, 2009) (FAA, 2007),
- e_{32} The management of change (ICAO, 2009) (FAA, 2007),
- e_{33} To solicit input through a non-punitive safety reporting system (FAA, 2007), and
- e_{34} Continuous improvement of the SMS (FAA, 2007).

***C_4* Safety promotion** (ICAO, 2009b)

Safety promotion component includes safety culture, training and education, safety communication and safety competency, and continuous improvement on elements. The employees of airport shall have current information and training relating to safety issue relevant to specific operation by airport safety manager. Airport provides appropriate training to all employees to accomplish an effected SMS via validated process.

- e_{41} Safety culture (FAA, 2007; TRB, 2007),
- e_{42} Training and education (ICAO, 2009b),
- e_{43} Safety communication (ICAO, 2009b), and
- e_{44} Safety competency and continuous improvement (FAA, 2007) (TRB, 2007).

They are summarized to the detailed safety elements under their corresponding components and definitions are listed in Table 4-3.

Table 4- 3 The definitions of airport SMS components and elements

Components	Elements	Definition
***C*₁** Safety policy and objectives (ICAO, 2009b)	***e*₁₁** Management commitment and responsibility (ICAO, 2009b)	1. Safety policy shall be in accordance with international and national requirements, and shall be signed by the accountable executive of the organization. 2. The safety policy shall reflect organizational commitments regarding safety; shall include a clear statement about the provision of the necessary resources for the implementation of the safety policy. 3. The safety policy shall include the safety reporting procedures; shall clearly indicate which types of operational behaviors are unacceptable; and shall include the conditions under which disciplinary action would not apply. 4. The safety policy shall be periodically reviewed to ensure it remains relevant and appropriate to the organization.
	***e*₁₂** Safety accountabilities (ICAO, 2009b)	1. The certified airport shall identify the accountable executive who, irrespective of other functions, shall have ultimate responsibility and accountability, on behalf of the certified aerodrome, for the implementation and maintenance of the SMS. 2. The certified airport shall also identify the accountabilities of all members of management, irrespective of other functions, as well as of employees, with respect to the safety performance of the SMS.
	***e*₁₃** Appointment of key safety personnel (ICAO, 2009b)	The certified airport shall identify a safety manager to be the responsible individual and focal point for the implementation and maintenance of an effective SMS.
	***e*₁₄** Coordination of emergency response planning (ICAO, 2009b)	1. The certified aerodrome shall ensure that an emergency response plan that provides for the orderly and efficient transition from normal to emergency and the return to normal operations. 2. The certified aerodrome is properly coordinated with the emergency response plans of those organizations it must interface with during the provision of its services.

Table 4- 3 The definitions of airport SMS components and elements (Cont.)

Components	Elements	Definition
***C*1** Safety policy and objectives (ICAO, 2009b)	***e* 15** SMS documentation (ICAO, 2009b)	1. The organization shall develop and maintain SMS documentation describing (1) The safety policy and objectives, (2) The SMS requirements, the SMS processes and procedures, and (3) The accountabilities, responsibilities and authorities for processes and procedures, and the SMS outputs. 2. The certified aerodrome shall develop and maintain a Safety Management Systems manual (SMSM), to communicate its approach to the management of safety throughout the organization.
***C*2** Safety risk management (ICAO, 2009)	***e* 21** Hazard identification (FAA, 2007)	1. Hazard identification shall be based on a combination of reactive, proactive and predictive methods of safety data collection. 2. The hazard identification stage considers all the possible sources of system failure which should include: (1) The equipment (example: construction equipment on a movement surface), (2) Operating environment (example: cold, night, low visibility), (3) Human element (example: shift work), (4) Operational procedures (example: staffing levels), and (5) Maintenance procedures (example: nightly movement area inspections by airport electricians). (6) External services (example: ramp traffic by Fixed-Base Operator (FBO) or law enforcement vehicles)
	***e* 22** Safety risk assessment system (FAA, 2007)	The airport operator shall estimate the level of risk such as by using the **predictive risk matrix** (see Fig. 4-3). Risk is the composite of the predicted severity and likelihood of the outcome or effect (harm) of the hazard in the worst credible system state.

Table 4- 3 The definitions of airport SMS components and elements (Cont.)

Components	Elements	Definition
***C*₂** Safety risk management (ICAO, 2009)	***e* 23** Safety risk mitigation strategies (FAA, 2007)	The risk levels used in predictive risk matrix can be defined as: 1. High risk- Unacceptable level of risk: The proposal cannot be implemented or the activity continued unless hazards are further mitigated so that risk is reduced to medium or low level. 2. Medium risk- Acceptable level of risk: Minimum acceptable safety objective; the proposal may be implemented or the activity can continue, but tracking and management are required. 3. Low risk- Acceptable without restriction or limitation.
	***e* 24** To implement, track and monitor the safety risk mitigation (FAA, 2007)	1. High risk- Tracking and management involvement are required, and management must approve any proposed mitigating controls. Catastrophic hazards that are caused by: (1) Single-point events or failures, (2) Common-cause events or failures, and (3) Undetectable latent events in combination with single point or common cause events are considered high risk, even if extremely remote. 2. Medium risk- Acceptable level of risk: the proposal may be implemented or the activity can continue, but tracking and management are required. 3. Low risk- the identified hazards are not required to be actively managed, but are documented.
***C*₃** Safety assurance (ICAO, 2009)	***e* 31** Safety performance monitoring and measurement (FAA, 2007)	Safety Assurance includes self-auditing, external auditing, and safety oversight. Safety oversight can be achieved through auditing and surveillance practices, given the diverse activities at commercial airports.
	***e* 32** The management of change (ICAO, 2009b)	The certified aerodrome shall develop and maintain a formal process to identify changes within the organization which may affect established processes and services; to describe the arrangements to ensure safety performance before implementing changes; and to eliminate or modify safety risk controls that are no longer needed or effective due to changes in the operational environment.

Table 4- 3 The definitions of airport SMS components and elements (Cont.)

Components	Elements	Definition
	e $_{33}$ A non-punitive safety reporting system (FAA, 2007)	1. The SMS should include a visible non-punitive safety reporting system supported by management. 2. The safety reporting system should permit feedback from personnel regarding hazards and safety-related concerns. 3. The SMS should use this information to identify and address safety deficiencies. The safety reporting system may also identify and correct non-conformance to safety policy.
	e $_{34}$ Continuous improvement of the SMS (ICAO, 2009b)	The certified aerodrome shall develop and maintain a formal process to identify the causes of substandard performance of the SMS, determine the implications of substandard performance of the SMS in operations, and eliminate or mitigate such causes.
C $_{4}$ Safety promotion (ICAO, 2009)	***e*** $_{41}$ Safety culture (FAA, 2007; TRB, 2007)	1. It requires a commitment to safety on the part of senior management. The attitudes, decisions and methods of operation at the policy-making level demonstrate the priority given to safety. 2. In effective safety cultures, there are clear reporting lines, clearly defined duties and well understood procedures. 3. Personnel fully understand their responsibilities and know what to report, to whom and when. 4. Senior management reviews not only the financial performance of the organization but also its safety performance.
C $_{4}$ Safety promotion (ICAO, 2009)	***e*** $_{42}$ Training and education (ICAO, 2009b)	The certified aerodrome shall develop and maintain a safety training programme that ensures that personnel are trained and competent to perform the SMS duties. The scope of the safety training shall be appropriate to each individual's involvement in the SMS.

Table 4- 3 The definitions of airport SMS components and elements (Cont.)

Components	Elements	Definition
***C*₄** Safety promotion (ICAO, 2009)	***e*** $_{43}$ Safety communication (FAA, 2007)	1. The certified aerodrome shall develop and maintain formal means for safety communication that ensures that all personnel are fully aware of the SMS, conveys safety-critical information, and explains why particular safety actions are taken and why safety procedures are introduced or changed. 2. Systems safety improvement will occur most efficiently if staff and employees are actively encouraged to identify potential hazards and propose solutions. Some examples of organizational communication are: (1) Safety seminars, (2) Safety letters, notices and bulletins, (3) Safety lessons-learned, (4) Bulletin boards, safety reporting drop boxes, and electronic reporting through web sites or email, (5) A method to exchange safety-related information with other airport operators through regional offices or professional organizations, and (6) Airport web-based safety reporting system currently being used by air operators.
	e $_{44}$ Safety competency and continuous improvement (FAA, 2007; TRB, 2007)	The Safety Manager provides current information and training relating to safety issues relevant to the specific operation of the airport. The provision of appropriate training to all staff, regardless of their level in the organization, is an indication of management's commitment to an effective SMS. Safety training and education should consist of the following: (1) A documented process to identify training requirements, (2) A validation process that measures the effectiveness of training, (3) Initial (general safety) job-specific training, (4) Recurrent safety training, (5) Indoctrination/initial training incorporating SMS, and (6) Training that includes human factors and organizational factors.

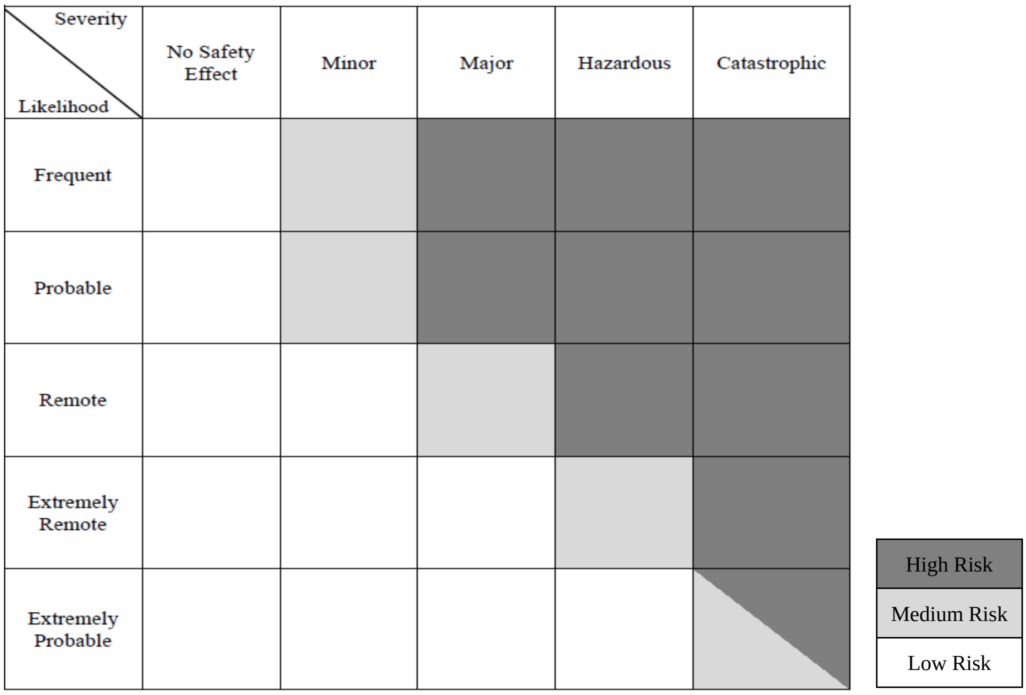


Fig. 4- 3 Predictive Risk Matrix

Source: FAA (2007)

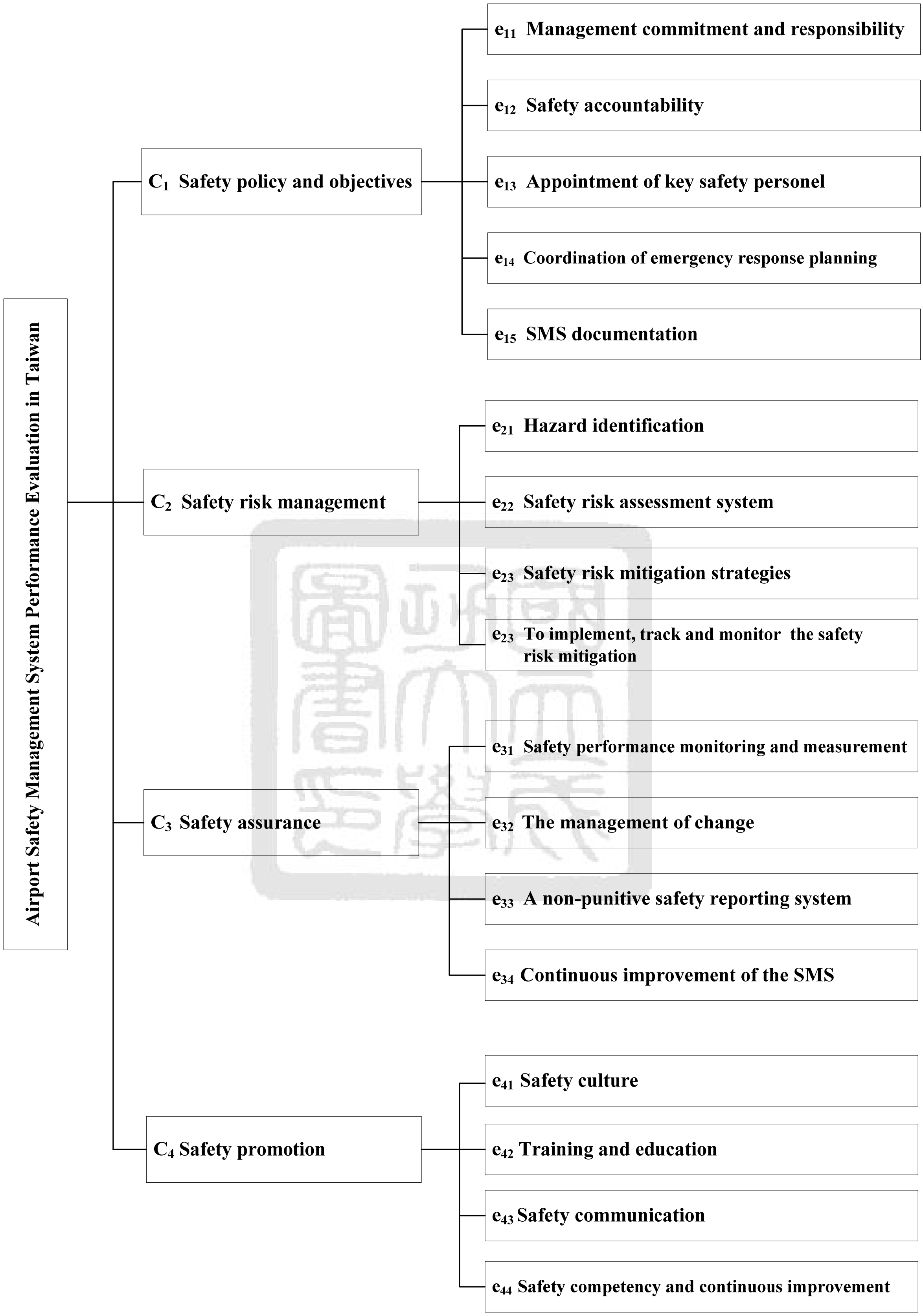


Fig. 4- 4 Taiwan Airport SMS performance evaluation structure

4.3 Performance by Fuzzy set theory

In many situations where performance rating and weights cannot be given precisely, the fuzzy set theory can be use to model the uncertainty of human judgments and the fuzzy multiple criteria decision making (FMCDM). Fuzzy set theory was first introduced by Zadeh (1965) for dealing uncertainty and imprecision associated with information. The preliminary of fuzzy set used for fuzzy TOPSIS method to be utilized in this study is defined as follows:

Definition 1: Fuzzy set

In a universe of discourse X a fuzzy set $\tilde{a}$ is characterized by a membership function $\mu_{\tilde{a}}(x)$ which associates each element x in X, a real number in the interval $[0,1]$. Membership function $\mu_{\tilde{a}}(x)$ is termed as grade of membership of x in $\tilde{a}$ (Zadeh, 1965), where

$$\tilde{a} = \{x,\ \mu_{\tilde{a}}(x) \mid x \in X\} \tag{4-1}$$

Definition 2: Fuzzy numbers

A fuzzy number is a quantity whose value is imprecise, rather than exact as is the case with "ordinary" (single-valued) numbers. Any membership function of fuzzy set number can be thought of as a function whose domain is a specified set, usually the set of real numbers, and whose range is span of non-negative real numbers between, and including, 0 and 1. Each numerical value in the domain is assigned a specific “grade of membership”, where 0 represents the smallest possible grade, and 1 is the largest possible grade (see Fig. 4-5).

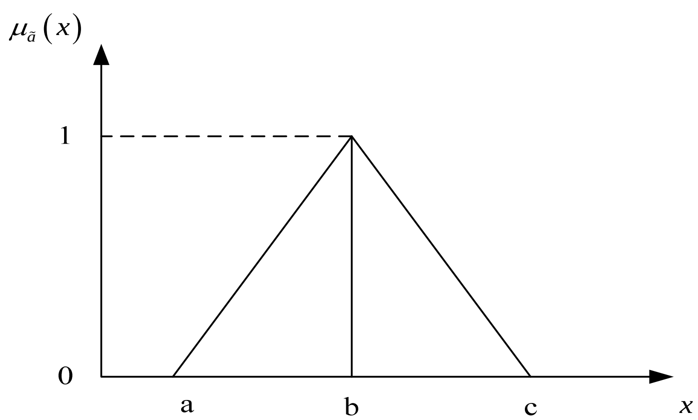


Fig. 4- 5 The membership function of a triangular fuzzy number $\tilde{a} = (a,b,c)$.

In this thesis triangular fuzzy numbers are used. In general, a triangular membership function is described by a triplet $\tilde{a}=(a,b,c)$ as shown in Fig. 4-5. A triangular fuzzy set $\tilde{a}=(a,b,c)$ and its associated membership function are defined as follows (Zadeh, 1965):

$$\mu_{\tilde{a}}(x)=\begin{cases}0, & x\le a\\ \dfrac{x-a}{b-a}, & a<x\le b\\ \dfrac{c-x}{c-b}, & b<x\le c\\ 0, & x>c\end{cases} \tag{4-2}$$

Definition 3: Calculate the distance of triangular fuzzy numbers

Let $\tilde{a}_1=(a_1,b_1,c_1)$ and $\tilde{a}_2=(a_2,b_2,c_2)$ be two triangular fuzzy numbers, then the vertex method is defined to calculate the distance between them as

$$d\left(\tilde{a}_1,\tilde{a}_2\right)=\sqrt{\frac{1}{3}\left[\left(a_1-a_2\right)^2+(b_1-b_2)^2+(c_1-c_2)^2\right]} \tag{4-3}$$

Definition 4: Calculate the distance of real triangular fuzzy numbers

Assuming that the numbers in the fuzzy sets $\tilde{a}_1=(a_1,b_1,c_1)$ and $\tilde{a}_2=(a_2,b_2,c_2)$ are real numbers, then the distance measurement $d\left(\tilde{a}_1,\tilde{a}_2\right)$ is identical to the Euclidean distance between two points in a three-dimensional space (Chen, 2000).

Definition 5: Comparing the distance of real triangular fuzzy number

Let $\tilde{a}_1$, $\tilde{a}_2$ and $\tilde{a}_3$ be three triangular fuzzy sets. The fuzzy number, $\tilde{a}_2$ is closer to fuzzy set, $\tilde{a}_1$ than other fuzzy set, $\tilde{a}_3$ if, and only if, $d\left(\tilde{a}_1,\tilde{a}_2\right)<d\left(\tilde{a}_1,\tilde{a}_3\right)$.

Based on the extension principle (Zadeh, 1965), the arithmetic operations of triangular fuzzy sets are as follows:

$$\tilde{a}_1+\tilde{a}_2=\left(a_1+a_2,b_1+b_2,c_1+c_2\right) \tag{4-4}$$

$$\tilde{a}_1-\tilde{a}_2=\left(a_1-a_2,b_1-b_2,c_1-c_2\right) \tag{4-5}$$

$$\tilde{a}_1\times\tilde{a}_2=\left(a_1\times a_2,b_1\times b_2,c_1\times c_2\right) \tag{4-6}$$

$$\tilde{a}_1 \times k = \left(a_1 \times k, b_1 \times k, c_1 \times k\right), \text{ for any real value } k \in X \tag{4-7}$$

$$\tilde{a}_1 / \tilde{a}_2 = \left(a_1/c_2,\ b_1/b_2,\ c_1/a_2\right) \tag{4-8}$$

Definition 6: Linguistic variables

A linguistic variable is a variable whose values are expressed in linguistic terms. The linguistic variable is a very helpful concept for dealing with situations where there are too complex or not well defined enough to be reasonably described by traditional quantitative expression (Zadeh, 1965). This study utilizes linguistic variable (Chen and Hwang, 1992) to evaluate the performance of an element as Very Low, Low, Medium, High or Very High. For example: the linguistic variable scale of the airport SMS performance can be classified: Very Low = (1, 1, 3), Low = (1, 3, 5), Medium = (3, 5, 7), High = (5, 7, 9) and Very High.= (7, 9, 9).

Principles of fuzzy linguistic variable scale is described below: the minimum (maximun) value of a triangular fuzzy set must be larger (smaller) than the maximum (minimum) value to the left (right) side of its adjacent triangular fuzzy set. Based on aforesaid principles and the natures of airport SMS elements, the five-level linguistic variable scale is constructed as Fig. 4-6.

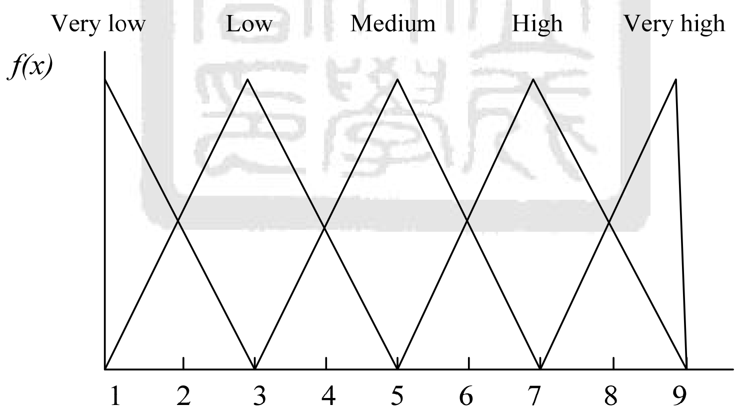


Fig. 4- 6 The five-level linguistic variable scale by fuzzy triangular sets

Source: Chen and Hwang (1992)

4.4 Performance by Fuzzy TOPSIS

Technique of Ordering Preference by Similarity to Ideal Solution (TOPSIS) was developed by Hwang and Yoon (1981) and was classified into MADM method (Zhang, 2004). The main concept of TOPSIS is to compare the MCDM criterions and to check if a judgment of a component has the shortest and farthest distances from the Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS). The MCDM problems are related to vague characters of criterions and subjective opinion by decision makers. In order to solve the qualitative, imprecise, and ill-structured decision problems (ill-structured), Zadeh (1965) proposed the theory of fuzzy sets, and suggested using the theory of fuzzy sets to as a tool to solve a complex system.

In real life, the human judgments embrace preference and subjective, and have vague nature (Chen, 2000). So, the linguistic assessments are widely used to evaluate elements by qualitative criterions, so that the rating of criterions can be obtained (see Section 3.2.3). Based on the qualitative natures of airport SMS components and elements, this study uses fuzzy TOPSIS to solve the performance evaluation of airport SMS for Taiwan airport. The International Air Transport Association (IATA) airport Code for TPE, KHH and TSA stand for Taoyuan, Kaohsiung and Taipei Songshang international airport.

The fuzzy TOPSIS approach is described as follows (Chen, 2000):

Step 1: Construct the fuzzy decision matrix

Assume that there are m international airports (or called systems) denoted by A_i $(i=1,2,\ldots,m)$, and n elements associated with each airport SMS performance assessments denoted by E_j $(j=1,2,\ldots,n)$. Then, the fuzzy decision matrix can be expressed in matrix form as in Eq. (4-9)

$$\tilde{D}=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array}\begin{array}{c} \begin{array}{cccc} E_1 & \mathrm{E}_2 & \cdots & E_n \end{array} \\ \begin{bmatrix} \tilde{a}_{11} & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & \tilde{a}_{22} & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{m1} & \tilde{a}_{m2} & \cdots & \tilde{a}_{mn} \end{bmatrix} \end{array}, \tag{4-9}$$

where $\tilde{a}_{ij}=(a_{ij}^{(L)},a_{ij}^{(M)},a_{ij}^{(U)})$ is the performance rating assessed by linguistic fuzzy triangular sets of the ith international airport A_i with respect to the jth elements E_j, $i=1,2,\ldots,m$ and $j=1,2,\ldots,n$. Note that these $(a_{ij}^{(L)},a_{ij}^{(M)},a_{ij}^{(U)})$ represent the aggregate values of the (fuzzy triangular lower, medium and upper numbers), obtained from a group of experts. In our study, n=17, E_1~E_5 stand for elements e_{11}~e_{15} under component C_1, E_6~E_9 for e_{21}~e_{24} under component C_2, E_{10}~E_{13} for e_{31}~e_{34} under component C_3, and E_{14} ~E_{17} for e_{41} ~e_{44} under component C_4.

Step 2: Construct the weighted fuzzy normalized decision matrix

Based on the natures of each airport SMS components and elements, this study constructs the weighted fuzzy normalized decision matrix. The weights of the components and elements are obtained by ANP process discussed in Section 3.2.1. The weighted normalized decision matrix $\tilde{V}$ is defined as

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{mxn}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \tag{4-10}$$

when

$$\tilde{v}_{ij} = \tilde{a}_{ij} \times w_{ij} \tag{4-11}$$

where $\tilde{w}_{ij}$ is weight of component C_j associated with airport A_i obtained from limiting supermatrix, and $\tilde{v}_{ij} = (v_{ij}^{(L)}, v_{ij}^{(M)}, v_{ij}^{(U)})$.

Step 3: Determine the fuzzy positive idea solution (FPIS) and fuzzy negative idea solution (FNIS)

Before the process of acquiring FPIS and FNIS, the defuzzification should be performed and then to compare the size of the fuzzy sets and obtain the largest and smallest sets for producing the FPIS and FNIS. This study utilizes the common method for Center of Gravity Defuzzification (CGD) (Yager, 1980), which is defiled as Eq. (4-12). That is, take the average of the numbers in the aggregate fuzzy set

$$B(\tilde{v}_{ij}) = \frac{\left(v_{ij}^{(L)} + v_{ij}^{(M)} + v_{ij}^{(U)}\right)}{3}. \tag{4-12}$$

As this step the FPIS and FNIS are defined as

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*), B(\tilde{v}_j^*) = \max_i B(\tilde{v}_{ij}),\ j = 1, 2, \ldots, n \tag{4-13}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-), B(\tilde{v}_j^-) = \min_i B(\tilde{v}_{ij}),\ j = 1, 2, \ldots, n. \tag{4-14}$$

Step 4: Calculate the distance of each airport SMS elements to FPIS and FNIS by using the distance of each element from A^* and A^- as calculated by

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*),\ i = 1, 2, \ldots, m, \tag{4-15}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-),\ i = 1, 2, \ldots, m, \tag{4-16}$$

where $d(\cdot\ ,\ \cdot)$ is the distance measurement between two fuzzy sets of numbers as defined in

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*) = \sqrt{\frac{1}{3}\left[(v_{ij}^{(L)} - v_j^{*(L)})^2 + (v_{ij}^{(M)} - v_j^{*(M)})^2 + (v_{ij}^{(U)} - v_j^{*(U)})^2\right]} \quad (4\text{-}17)$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^-) = \sqrt{\frac{1}{3}\left[(v_{ij}^{(L)} - v_j^{-(L)})^2 + (v_{ij}^{(M)} - v_j^{-(M)})^2 + (v_{ij}^{(U)} - v_j^{-(U)})^2\right]} \quad (4\text{-}18)$$

where d_i^* and d_i^- are , respectively, the FPIS and FNIS for the i^{th} system (airport).

Step 5: To obtain the closeness coefficient and to rank the order of airport SMS elements
A closeness coefficient (CC) is used to determine the ranking order of all airports once the d_i^* and d_i^- for each airport of $A_i (i = 1, 2, \ldots, m)$ have been calculated. The closeness coefficient (CC_i) of the i^{th} airport is defined as

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-},\ i = 1, 2, \ldots, m. \quad (4\text{-}19)$$

The value of CC_i lies in the interval of (0, 1). It implies that, an airport (A_i) is closer to the FPIS (A^*) and farther away from FNIS(A^-) as the value of CC_i approaches 1. Therefore, using to the closeness coefficient, this study can easily determine the ranking order of all airports and select the best from them.

4.5 Stage of data collection

There are three stages of expert questionnaire survey in this study and the area of experts' background includes aviation industries, government, and academic area. The operations of questionnaire investigating are divided into three stages which are described as follows:

Stage 0: After establishing the airport SMS performance evaluation components and elements via literature and regulations reviewing, the initial stage airport SMS questionnaires where designed at this stage. Before sending questionnaires at following stages, three selected experts are invited to examine the validity of the contents. Their backgrounds are in government, aviation industry and academic areas with average working seniority of 17 years.

Stage 1: There are two purposes at this stage: the first one is to construct a dependency network of the airport SMS components via SMS manual reviewing, experts' interview, and conduct a Pearson correlation analysis (Hsu, 2009); the second one is to obtain the weights of components and elements via relative importance assessment by ANP method. For the reason for proceeding Pearson correlation analysis, this study uses Table 4-4 to collect each individual assessment on a component with scores ranging from 1 to 10, where a higher score means more important. For example, a score of 6 for component C_1 in Table 4-3 is slight higher than the average.

Table 4- 4The assessment of airport SMS individual component importance

Importance score	1	2	3	4	5	6	7	8	9	10
C_1						★				

In order to obtain the weights of components and elements, ANP method is used via the relative importance scores by verbal judgment as shown in Table 4-5. For example in Table 4-4, the component C_1 is compared to components C_2, C_3 and C_4 and obtain the relative importance by C_1 verbal judgment using "Strong (4:1)", "Marginally strong (2:1) and "Weak (1:5)". There are about 17 experts who worked more than 10 years to participate at the stage one survey. In to the group decision problem expert questionnaire the numbers are 5~15 (Teng, 2005); for this reason, this study has sent 17 questionnaires to experts. SAS 9.3 program and Super Decision 2.2.3 software are utilized to code and analyze the data. The content of questionnaire at stage 1 is shown in Appendix 4.

Table 4- 5 Relative importance assessment for airport SMS components and elements

C_i [a]	Verbal judgment scale of relative importance																	C_i [a]
	Extremely strong		Very strong		Strong		Marginally strong		Equal	Marginally weak		Weak		Very weak		Extremely weak		
scale	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	scale
C_1						★												C_2
								★										C_3
													★					C_4

[a] There are i components $(C_i,\ i = 1, 2, 3 \text{ and } 4)$.

Stage 2: The main purpose at this stage is to evaluate the airport SMS performance by components and elements for TPE, KHH and TSA in Taiwan. Stage 2 uses the expert questionnaires to obtain the airport SMS performance scores via linguistic variables for each component and element (see Table. 4-6). Due to the scarcity of professional personnel in airport safety management, this study has invited 22 experts to evaluate the airport SMS performance, but only 17 of them were available. Their backgrounds are in aviation industries, government, and academic area (see Table. 4-7). By statistical theory a sample of experts ranging from 15 to 25 would be sufficient to provide needed information. At this stage, Excel 2007 software is utilized to code and analyze the data. The content of the questionnaires at stage 2 is shown in Appendix 5.

Table 4- 6 Performance by linguistic variables for a component or an element

Linguistic variables	Very low	Low	Medium	High	Very high
Performance Score	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

Table 4- 7 The background of experts for two stages of research in Part two

Experts No.	Work area	Title	Work seniority
1	Airlines (Aviation Industries)	Executive Vice President	22
2		Special Assistant / Pilot	12
3		Executive Vice President	26
4		Manager	10
5	Airport Service Company (Aviation Industries)	Executive Vice President	28
6	Aviation Safety Council (Government Area)	Manager Director	11
7		Chief of Aviation Safety Division	14
8		Vice investigator	17
9		Consultant	10
10	Civil Aeronautics Administrators (Government Area)	Chief of Aerodrome Management	34
11		Vice Chief of Air Transport Division	13
12		Engineer [a]	15
13		Director of Airport Office [b]	20
14	Academic area	Professor	29
15		Professor	26
16		Associate Professor	11
17		Assistant Professor	17
18		Assistant Professor	10

[a] All experts attended two stages of survey, except expert No.12 at stage one survey.
[b] All experts attended two stages of survey, except expert No.13 at stage two survey.

4.6 Empirical Study of Airport SMS performance evaluation

Based on the objective of the research in Part 2, the airport SMS performance of three international airports, TPE, KHH and TPE, is evaluated by experts in the empirical study. Before empirical survey of airport SMS performance, this research confirms the SMS implementation plan of TPE (Taoyuan International Airport Corporation (TIAC), 2012), KHH (CAA, 2012a) and TSA (CAA, 2012b). Because the SMS implementation plan is a realistic strategy which meets the organization's approach to managing safety while supporting effective and efficient delivery of service (ICAO, 2009a). The progress of SMS implementation plan for TPE, KHH and TSA are shown as Table 4-8. In order to present the realistic airport SMS implementation of target airports at the stage 2 survey, the SMS manuals of TPE (TIAC, 2012), KHH (CAA, 2012a) and TSA (CAA, 2012b)were sent with the stage 2 questionnaires to experts.

Two stages of expert questionnaire surveys were undergone from September 08, 2012 to October 30, 2012, and the experts involved in the surveys are in the groups of airlines industry, government, and academic area (see Table. 4-7). The response rates of experts' questionnaire surveys are shown in Table 4-9. After the two stages of expert questionnaire surveys, this research interviews three top airport SMS managers to discuss the results of airport SMS performance ranking, and the dates of interviews are scheduled on March 6 and 8 in 2013. The discussion of three airport's SMS managers are illustrated on Section 4.6.3, and the discussed questions are demonstrated on Appendix 6.

Table 4- 8 The progress of SMS implementation plan for TPE, KHH and TSA

Implementation stage [a]	Subject	TPE	KHH	TSA
Stage 1	Planning SMS implementation	Completed on Sep. 30, 2010	Completed on Sep. 30, 2010	Completed on Sep. 30, 2010
Stage 2	Safety Management Processes	Completed on Dec. 31, 2010	Completed on Dec. 31, 2010	Completed on Jun. 30, 2011
Stage 3	Operational Safety Assurance	Completed on on Sep. 30, 2011	Completed on on Sep. 30, 2011	Completed on on Sep. 30, 2011

Note: [a] The stages are included at stages 1 to 3.

Table 4- 9 The two stage questionnaire survey statistics

Implementation stage/period	Questionnaire State	Airlines industry	Government area	Academic area	Total	Return rate
Stage 1	Sending	5	11	5	21	---
From September 08 to 30, 2012	Returning	5	7	5	17	80.95%
Stage 2	Sending	5	12	5	22	---
From October 01to 31 2012	Returning	5	7	5	17	77.27%

4.6.1 The weights of airport SMS

The first stage expert questionnaire survey focuses on two parts: the first one is to determine the airport SMS components interactive network, and the second one is to obtain the weights of components and elements via ANP method. The results of stage 1 are described by the following steps:

Step 1: To decompose the problem as a model structure:

At this stage, the construction of a network dependency of the airport SMS components is according to SMS manual reviewing, expert's interviews and Pearson correlation coefficient analysis (Hsu, 2009) and Spearman rank coefficient analysis. Depend on the real operations of each SMS component, this study defines the inner loops by the natures of feedback under SMS elements, if the component has the nature from elements, the inner feedback is determined. For example, elements e_{21} and e_{24} have the nature of feedback to component C_2, which indicate component C_2 has inner loop as shown in Fig. 4-7. Referring to Table 4-3, the natures of feedback descriptions of airport SMS components and elements are shown as Table 4-10; based on the relationships of feedback in the inner dependency network, this structure is then formed. This study is based on the contents of Table 4-10 to decide if the feedback nature is appropriate for the components.

Table 4- 10 The Nature of feedback descriptions under Airport SMS components

Components	Nature of feedback descriptions
C_2	e_{21}: Safety data collection is based on a combination of reactive, proactive and predictive methods; it is general concept.
	e_{23}: Three risk levels are used in predictive risk matrix in an actively continuous way until hazards are further mitigated so that risk is reduced to medium or low level.
	e_{24}: Tracking and management involvement are required for safety risk mitigation.
C_3	e_{31}: Safety Assurance includes self-auditing, external auditing, and survey oversight.
	e_{34}: Continuous improvement of the SMS; it is partially connected with $e_{31.}$
C_4	e_{42}: To develop maintain a safety training programme that ensures the personnel are trained and competent to perform the SMS duty.
	e_{44}: A validation process that measures the effectiveness of training and recurrent safety training.

The result of Pearson correlation coefficient analysis is shown in Table 4-11. All components are correlated with positive relationship, except insignificant relation between C_1 and C_3. Using the level of significance being 0.05, the most significant correlation is between C_2 and C_3 (p-value= 0.0095) and the next one is between C_1 and C_4 (p-value= 0.0142).

Although the correlation between components C_1 and C_2 is weak with the coefficient of 0.11292 (p-value=0.6210) by experts survey (see Table 4-11), the elements *Management commitment and responsibility* (e_{11}), *Safety accountabilities* (e_{12}) and *Appointment of key safety personnel* (`e_{13}) are affected each other in operation to the three elements including *Hazard identification* (e_{21}), *Safety risk assessment system* (e_{22}), *Safety risk mitigation strategies* (e_{23}) and *To implement, track and monitor the safety risk mitigation* (e_{24}) (see Table 4-3). In other words, *Safety policy and objectives* (C_1) and *Safety risk management* (C_2) are mutually related.

Table 4- 11 Analysis of Pearson correlation for airport SMS components

Pearson Correlation Coefficients				
Components	C_1	C_2	C_3	C_4
C_1	1.0000	0.l292	-0.0216	0.5822
(p-value)	---	(0.6210)	(0.9342)	(0.0142)
C_2	0.1292	1.0000	0.6088	0.2215
(p-value)	(0.6210)	---	(0.0095)	(0.3929)
C_3	-0.0216	0.6088	1.0000	0.2952
(p-value)	(0.9342)	(0.0095)	---	(0.2499)
C_4	0.5822	0.2215	0.2952	1.0000
(p-value)	(0.0142)	(0.3929)	(0.2499)	---

In order to understand the affect on parameters and to avoid extreme values, this study also uses the Spearman rank correlation to verify the relationship between the four components, and the coefficients are close to, but slightly lower than those of Pearson correlation coefficients (see Table 4-12). The general trends are consistent.

Table 4- 12 Analysis of Spearman rank correlation for airport SMS components

Spearman Rank Correlation Coefficients				
Components	C_1	C_2	C_3	C_4
C_1	1.0000	0.1096	-0.0506	0.5615
(p-value)	---	(0.6754)	(0.8471)	(0.0190)
C_2	0.1096	1.0000	0.6342	0.2737
(p-value)	(0.6754)	---	(0.0063)	(0.2878)
C_3	-0.0506	0.6342	1.0000	0.3402
(p-value)	(0.8471)	(0.0063)	---	(0.1815)
C_4	0.5615	0.2737	0.3402	1.0000
(p-value)	(0.0190)	(0.2878)	(0.1815)	---

According to the results at step one, this study combines the relationships of components and develops the dependency network of the airport SMS (see Fig. 4-7). No feedback within component C_1. Other three components (C_2, C_3 and C_4) have feedback for the inner dependency network, and further, there are five interrelations for the airport SMS components as: C_1 and C_2, C_1 and C_4, C_2 and C_3, C_2 and C_4, and C_3 and C_4. The details routes of interactions for all components are summarized in Table 4-13.

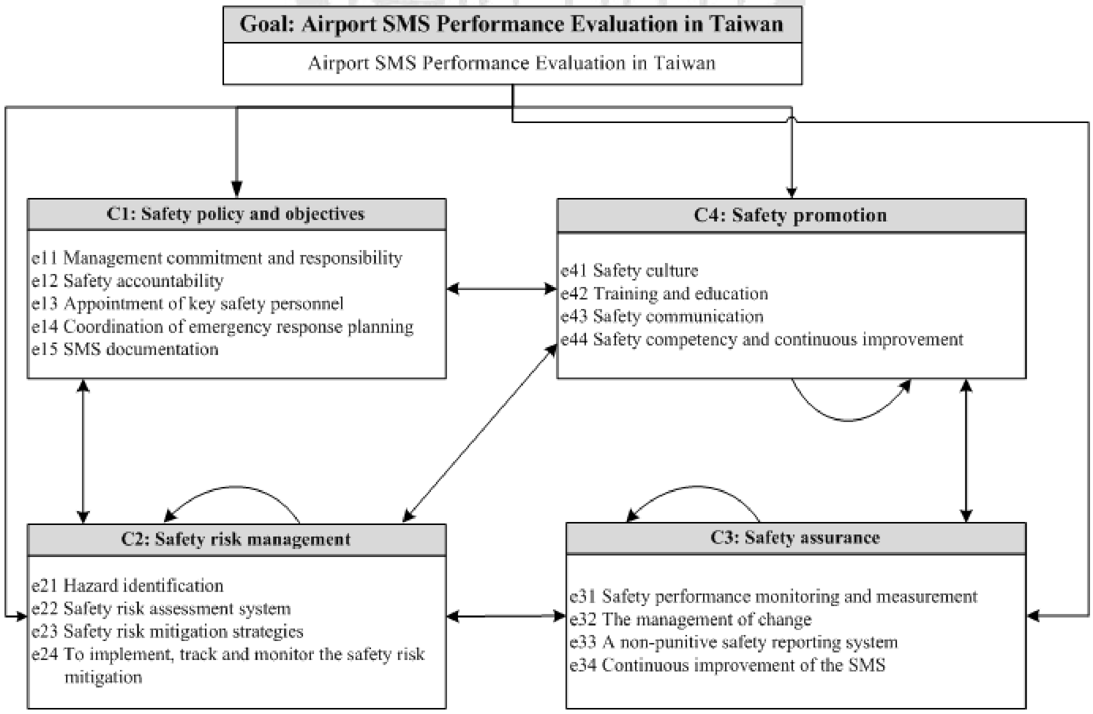


Fig. 4- 7 The dependency network of the airport SMS

Table 4- 13 The routes of interactions for all components

Components	Route in the dependency network	Feedback loop
C_1	C_1 to C_2, C_1 to C_4,	Nil
C_2	C_2 to C_1 C_2 to C_3 C_2 to C_4	C_2 to C_2
C_3	C_3 to C_2 C_3 to C_4	C_3 to C_3
C_4	C_4 to C_1 C_4 to C_2 C_4 to C_3	C_4 to C_4

Step 2: Pair-wise comparison matrices:

According to the dependency network of the airport SMS (see Fig. 4-7 and Table 4-11), this study obtains the Pair-wise comparison matrices via experts' judgments by aggregated geometric mean and its rounding value. Tables 4-14 to 4-22 are the comparison matrixes of airport SMS components and elements under the goal in this study. For example in Table 4-13, the relative importance of C_1 to C_2 is 2 times, and in the opposite of relative importance C_2 to C_1 is 0.5 times that is a reciprocal of C_1 to C_2. The eigen-vector in the last column is the weight of the comparison matrix corresponding to the largest eigen-value.

In order to indentify the possible error in judgments of pair-wise comparison matrices, the Consistency ratio (CR) should be used and it should be less than 0.1 or so to be considered reasonably consistent (Saaty, 2008), in the following tables, all other comparison matrices have similar property as that of Table 4-14.

Table 4- 14 The comparison matrix under the goal of airport SMS performance evaluation

Under the goal of airport SMS components	C_1	C_2	C_3	C_4	**Eigenvector**
C_1: Safety policy and objectives	1.0	$\boxed{2.0}$	2.0	2.0	0.3952
C_2: Safety risk management	0.5	1.0	2.0	2.0	0.2781
C_3: Safety assurance	0.5	0.5	1.0	1.0	0.1634
C_4: Safety Promotion	0.5	0.5	1.0	1.0	0.1634
CI=0.0201; CR = 0.0227					

Table 4- 15 The comparison matrix under Component C_1

Under component C_1	**C_2**	**C_4**	**Eigenvector**
C_2: Safety risk management	1.0	2.0	0.6667
C_4: Safety promotion	0.5	1.0	0.3333
CI=0.0000, CR = 0.0000			

Table 4- 16 The comparison matrix under Component C_2

Under component C_2	**C_1**	**C_2**	**C_3**	**C_4**	**Eigenvector**
C_1: Safety policy and objectives	1.0	2.0	2.0	2.0	0.3952
C_2: Safety risk management	0.5	1.0	2.0	2.0	0.2781
C_3: Safety assurance	0.5	0.5	1.0	1.0	0.1634
C_4: Safety Promotion	0.5	0.5	1.0	1.0	0.1634
CI=0.0201, CR = 0.0227					

Table 4- 17 The comparison matrix under Component C_3

Under component C_3	**C_2**	**C_3**	**C_4**	**Eigenvector**
C_2: Safety risk management	1.0	2.0	2.0	0.50
C_3: Safety assurance	0.5	1.0	1.0	0.25
C_4: Safety promotion	0.5	1.0	1.0	0.25
CI=0.0000, CR = 0.0000				

Table 4- 18 The comparison matrix under Component C_4

Under component C_4	**C_1**	**C_2**	**C_3**	**C_4**	**Eigenvector**
C_1: Safety policy and objectives	1.0	2.0	2.0	2.0	0.3952
C_2: Safety risk management	0.5	1.0	2.0	2.0	0.2781
C_3: Safety assurance	0.5	0.5	1.0	1.0	0.1634
C_4: Safety promotion	0.5	0.5	1.0	1.0	0.1634
CI=0.0201, CR = 0.0227					

Table 4- 19 The comparison matrix of elements under Component C_1

Elements under component C_1	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	**Eigenvector**
e_{11} Management commitment and responsibility	1.00	3.00	2.00	3.00	3.00	0.3969
e_{12} Safety accountability	0.33	1.00	1.00	2.00	2.00	0.1879
e_{13} Appointment of key safety personnel	0.50	1.00	1.00	2.00	2.00	0.2010
e_{14} Coordination of emergency response planning	0.33	0.50	0.50	1.00	1.00	0.1071
e_{15} SMS documentation	0.33	0.50	0.50	1.00	1.00	0.1071
CI=0.0130, CR = 0.0117						

Table 4- 20 The comparison matrix of elements under Component C_2

Elements under component C_2	e_{21}	e_{22}	e_{23}	e_{24}	**Eigenvector**
e_{21} Hazard identification	1.0	2.0	2.0	2.0	0.40
e_{22} Safety risk assessment system	0.5	1.0	1.0	1.0	0.20
e_{23} Safety risk mitigation strategies	0.5	1.0	1.0	1.0	0.20
e_{24} To implement, track and monitor the safety risk mitigation	0.5	1.0	1.0	1.0	0.20
CI=0.0000, CR = 0.0000					

Table 4- 21 The comparison matrix of elements under Component C_3

Elements under component C_3	e_{31}	e_{32}	e_{33}	e_{34}	**Eigenvector**
e_{31} Safety performance monitoring and measurement	1.0	2.0	1.0	2.0	0.3383
e_{32} The management of change	0.5	1.0	1.0	1.0	0.2046
e_{33} A non-punitive safety reporting system	1.0	1.0	1.0	2.0	0.2879
e_{34} Continuous improvement of the SMS	0.5	1.0	0.5	1.0	0.1692
CI=0.0201, CR = 0.0227					

Table 4- 22 The comparison matrix of elements under Component C_4

Elements under component C_4	e_{41}	e_{42}	e_{43}	e_{44}	**Eigenvector**
e_{41} Safety culture	1.0	1.0	1.0	2.0	0.2857
e_{42} Training and education	1.0	1.0	1.0	2.0	0.2857
e_{43} Safety communication	1.0	1.0	1.0	2.0	0.2857
e_{44} Safety competency and continuous improvement	0.5	0.5	0.5	1.0	0.1429
CI=0.0000, CR = 0.0000					

Step 3: Supermatrix formation:

The formation of supermatrix is established by four parts through the product process and is described as below:

A. The cluster matrix

The cluster matrix is made of the eigenvectors under each component, which is used to compute the relative importance of components and it is used to weigh the corresponding unweighted sub-matrices in the calculations. In Table 4-23, this study establishes the priorities for the cluster impact of each component under the goal of airport SMS performance evaluation, where each column is summed to one.

Table 4- 23 The cluster weight with respect to each component

	C_1	C_2	C_3	C_4
C_1: Safety policy and objectives	0	0.3952	0	0.3952
C_2: Safety risk management	$\boxed{0.6667}$	0.2781	0.5	0.2781
C_3: Safety assurance	0	0.1634	0.25	0.1634
C_4: Safety Promotion	0.3333	0.1634	0.25	0.1634

B. Unweighted supermatrix

The unweighted supermatrix consists of eigenvectors obtained from various pair-wise comparison matrices in Step 2. There are 4 components in the airport SMS system which produce 4 by 4 (=16) comparison sub-matrices; the number of columns in the unweighted supermatrix is equal to the total number of columns of all comparison sub-matrices and the dimensions of unweighted sub-matrices under each component are 5, 4, 4, 4, respectively, which gives a total of 17 dimensions (see Table 4- 24). Note that W_{11} is a zero sub-matrix which represents no feedback within component C_1 while W_{22}, W_{33} and W_{44} do have influence of feedback completely or partially. The sub-matrices W_{12} and W_{14} are the same; W_{21}, W_{23} and W_{24} are the same; W_{31} and W_{34} are the same; and W_{41}, W_{42} and W_{43} are the same. This is because they have dependency as indicated in Fig. 4-7 and Table 4-13 at the initial stage.

C. Weighted supermatrix

The weighted supermatrix as shown in Table 4-25 is obtained by multiplying the submatrix (C_i to C_j) in the unweighted supermatrix by the weight of influence of the component (C_i to C_j) from the cluster matrix in Table 4-24. For example, the second entry in column C_1 in Table 4-23 (C_2 to C_1) is 0.6667, which is used to multiply each of 20 entries in the unweighted sub-supermatrix (C_2 to C_1) and shown in Table 4-24 by bold border lines, then this study can obtain the weighted sub-supermatrix of C_2 to C_1 as shown in Table 4-25 by bold border lines. The rest of the weighted sub-supermatrices are obtained by a similar way.

D. Limiting supermatrix

The limiting supermatrix is derived by raising the weighted supermatrix to a power of as 2k+1 as k goes to infinity, which is shown in Table 4-26. One can see that all column vectors in the stable supermatrix are exactly the same, which provide a long term priorities of weights on components and elements in the airport SMS system.

Step 4. Selection of the important elements or components:

As the supermatrix covers the whole network in Fig.4-7, the columns in the limiting supermatrix represent the final priorities of weights. Based on the average of all expert's responses under a component or an element the result can be or may be over-exaggerated by extreme values than that of geometric mean. Consequently, the results based on the average response in the pair-wise comparison may cause over estimation. However, the overall ranks for components are unchanged, only the elements under components have minor changes in ranks.

Based on the above results and suggestions by Saaty (1980), this study uses the geometric means to deal with the expert's responses via step 1 to step 4. The details of overall weight rankings in elements, the ranks of elements within a component and the ranks of all components are shown in Table 4-27, where the weight of each component is just the sum of weights of elements under it. The weight rankings of the airport SMS components from high to low are: *Safety risk management* (C_2) (0.3681), *Safety policy and objectives* (C_1) (0.2685), *Safety promotion* (C_4) (0.2153) and *Safety assurance* (C_3) (0.1480). The top five weight rankings of Airport SMS elements are: *Hazard identification* (e_{21}) (0.1276), *Management commitment and responsibility* (e_{11}) (0.1066), *Safety risk mitigation strategies* (e_{23}) (0.0884), *To implement, track and monitor the safety risk mitigation* (e_{24}) (0.0884), and *Safety performance monitoring and measurement* (e_{31}) (0.0679).

In order to understand the weights of components by grouping viewpoint, this study used the super decision software to produce the results (see Table 4-28). *Safety policy and objectives* (C_1) and *Safety risk management* (C_2) are the first and the second rank in Airline industries and Government group; *Safety risk management* (C_2) and *Safety policy and objectives* (C_1) are the top two ranking by Academic and overall viewpoint.

Table 4- 24 The unweighted supermatrix for the airport SMS components and elements

	Components	***C*₁**					***C*₂**				***C*₃**				***C*₄**			
Components	**Elements**	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{21}	e_{22}	e_{23}	e_{24}	e_{31}	e_{32}	e_{33}	e_{34}	e_{41}	e_{42}	e_{43}	e_{44}
C_1	e_{11}	0	0	0	0	0	0.3969	0.3969	0.3969	0.3969	0	0	0	0	0.3969	0.3969	0.3969	0.3969
	e_{12}	0	0	0	0	0	0.1879	0.1879	0.1879	0.1879	0	0	0	0	0.1879	0.1879	0.1879	0.1879
	e_{13}	0	0	0	0	0	0.2010	0.2010	0.2010	0.2010	0	0	0	0	0.2010	0.2010	0.2010	0.2010
	e_{14}	0	0	0	0	0	0.1071	0.1071	0.1071	0.1071	0	0	0	0	0.1071	0.1071	0.1071	0.1071
	e_{15}	0	0	0	0	0	0.1071	0.1071	0.1071	0.1071	0	0	0	0	0.1071	0.1071	0.1071	0.1071
C_2	e_{21}	0.4	0.4	0.4	0.4	0.4	0	0	0	0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	e_{22}	0.2	0.2	0.2	0.2	0.2	0	0	0	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	e_{23}	0.2	0.2	0.2	0.2	0.2	0	0	1	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	e_{24}	0.2	0.2	0.2	0.2	0.2	0	0	0	1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
C_3	e_{31}	0	0	0	0	0	0.3383	0.3383	0.3383	0.3383	1	0.6667	0.6667	0.6667	0.3383	0.3383	0.3383	0.3383
	e_{32}	0	0	0	0	0	0.2046	0.2046	0.2046	0.2046	0	0	0	0	0.2046	0.2046	0.2046	0.2046
	e_{33}	0	0	0	0	0	0.2879	0.2879	0.2879	0.2879	0	0	0	0	0.2879	0.2879	0.2879	0.2879
	e_{34}	0	0	0	0	0	0.1692	0.1692	0.1692	0.1692	0	0.3333	0.3333	0.3333	0.1692	0.1692	0.1692	0.1692
C_4	e_{41}	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0	0	0	0
	e_{42}	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0	1	0	0
	e_{43}	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0.2857	0	0	0	0
	e_{44}	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0	0	0	1

Table 4- 25 The weighted supermatrix fot the airport SMS components and elements

	Components	***C*$_1$**					***C*$_2$**				***C*$_3$**				***C*$_4$**			
Components	**Elements**	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{21}	e_{22}	e_{23}	e_{24}	e_{31}	e_{32}	e_{33}	e_{34}	e_{41}	e_{42}	e_{43}	e_{44}
C_1	e_{11}	0	0	0	0	0	0.2173	0.2173	0.1569	0.1569	0	0	0	0	0.1875	0.1569	0.1875	0.1569
	e_{12}	0	0	0	0	0	0.1029	0.1029	0.0743	0.0743	0	0	0	0	0.0888	0.0743	0.0888	0.0743
	e_{13}	0	0	0	0	0	0.1101	0.1101	0.0795	0.0795	0	0	0	0	0.0950	0.0795	0.0950	0.0795
	e_{14}	0	0	0	0	0	0.0586	0.0586	0.0423	0.0423	0	0	0	0	0.0506	0.0423	0.0506	0.0423
	e_{15}	0	0	0	0	0	0.0586	0.0586	0.0423	0.0423	0	0	0	0	0.0506	0.0423	0.0506	0.0423
C_2	e_{21}	0.2667	0.2667	0.2667	0.2667	0.2667	0	0	0	0	0.2	0.2	0.2	0.2	0.1329	0.1112	0.1329	0.1112
	e_{22}	0.1333	0.1333	0.1333	0.1333	0.1333	0	0	0	0	0.1	0.1	0.1	0.1	0.0665	0.0556	0.0665	0.0556
	e_{23}	0.1333	0.1333	0.1333	0.1333	0.1333	0	0	0.2781	0	0.1	0.1	0.1	0.1	0.0665	0.0556	0.0665	0.0556
	e_{24}	0.1333	0.1333	0.1333	0.1333	0.1333	0	0	0	0.2781	0.1	0.1	0.1	0.1	0.0665	0.0556	0.0665	0.0556
C_3	e_{31}	0	0	0	0	0	0.0766	0.0766	0.0553	0.0553	0.25	0.1667	0.1667	0.1667	0.0661	0.0553	0.0661	0.0553
	e_{32}	0	0	0	0	0	0.0463	0.0463	0.0334	0.0334	0	0	0	0	0.0400	0.0334	0.0400	0.0334
	e_{33}	0	0	0	0	0	0.0652	0.0652	0.0470	0.0470	0	0	0	0	0.0562	0.0470	0.0562	0.0470
	e_{34}	0	0	0	0	0	0.0383	0.0383	0.0276	0.0276	0	0.0833	0.0833	0.0833	0.0330	0.0276	0.0330	0.0276
C_4	e_{41}	0.0952	0.0952	0.0952	0.0952	0.0952	0.0647	0.0647	0.0467	0.0467	0.0714	0.0714	0.0714	0.0714	0	0	0	0
	e_{42}	0.0952	0.0952	0.0952	0.0952	0.0952	0.0647	0.0647	0.0467	0.0467	0.0714	0.0714	0.0714	0.0714	0	0.1634	0	0
	e_{43}	0.0952	0.0952	0.0952	0.0952	0.0952	0.0647	0.0647	0.0467	0.0467	0.0714	0.0714	0.0714	0.0714	0	0	0	0
	e_{44}	0.0476	0.0476	0.0476	0.0476	0.0476	0.0323	0.0323	0.0233	0.0233	0.0357	0.0357	0.0357	0.0357	0	0	0	0.1634

Table 4- 26 The limited supermatrix for the airport SMS components and elements

	Components	C_1					C_2				C_3				C_4			
Components	**Elements**	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{21}	e_{22}	e_{23}	e_{24}	e_{31}	e_{32}	e_{33}	e_{34}	e_{41}	e_{42}	e_{43}	e_{44}
C_1	e_{11}	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066	0.1066
	e_{12}	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505	0.0505
	e_{13}	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540	0.0540
	e_{14}	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287
	e_{15}	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287	0.0287
C_2	e_{21}	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276	0.1276
	e_{22}	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638	0.0638
	e_{23}	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884
	e_{24}	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884
C_3	e_{31}	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679
	e_{32}	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227	0.0227
	e_{33}	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320	0.0320
	e_{34}	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255	0.0255
C_4	e_{41}	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568
	e_{42}	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679	0.0679
	e_{43}	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568	0.0568
	e_{44}	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339	0.0339

Table 4- 27 The rankings of Airport SMS components and elements' weight

Component	**Elements**	**Limiting (Geo*)**	**Overall Ranking**	**Rank within component**	**Total weight**	**Rank of components**
C_1: Safety policy and objectives	e_{11} Management commitment and responsibility	0.1066	2	1	0.2685	2
	e_{12} Safety accountability	0.0505	11	3		
	e_{13} Appointment of key safety personnel	0.0540	10	2		
	e_{14} Coordination of emergency response planning	0.0287	14	4		
	e_{15} SMS documentation	0.0287	14	4		
C_2: Safety risk management	e_{21} Hazard identification	0.1276	1	1	0.3682	1
	e_{22} Safety risk assessment system	0.0638	7	4		
	e_{23} Safety risk mitigation strategies	0.0884	3	2		
	e_{24} To implement, track and monitor the safety risk mitigation	0.0884	3	2		
C_3: Safety assurance	e_{31} Safety performance monitoring and measurement	0.0679	5	1	0.1480	4
	e_{32} The management of change	0.0227	17	4		
	e_{33} A non-punitive safety reporting system	0.0320	13	2		
	e_{34} Continuous improvement of the SMS	0.0255	16	3		
C_4: Safety promotion	e_{41} Safety culture	0.0568	8	2	0.2153	3
	e_{42} Training and education	0.0679	6	1		
	e_{43} Safety communication	0.0568	8	2		
	e_{44} Safety competency and continuous improvement	0.0339	12	4		

* Geometric mean

Table 4- 28 The rankings of weights for Airport SMS components by groups and overall

Component	Airline	Rank	Gove. [a]	Rank	Acad. [b]	Rank	overall weight	Rank
C_1: Safety policy and objectives	0.4192	1	0.4000	1	0.2879	2	0.2685	2
C_2: Safety risk management	0.2970	2	0.2000	3[c]	0.3383	1	0.3682	1
C_3: Safety assurance	0.1444	3	0.2000	3[c]	0.2046	3	0.1480	4
C4: Safety promotion	0.1394	4	0.2000	3[c]	0.1692	4	0.2153	3

[a] Experts of government group ; [b] Experts of Academic group; [c] Average rank

4.6.2 The performance of airport SMS evaluation

As mentioned above, the linguistic assessments (see Fig. 4-5) are used to evaluate airport SMS elements via fuzzy numbers, and then the rating of elements can be obtained. This study uses fuzzy TOPSIS method to evaluated three international airport SMS performance (TPE, KHH and TSA), the operational steps and results are given below:

Step 1: Construct the fuzzy decision matrix

After aggregating the expert's assessments by geometric mean using fuzzy sets, the airport SMS elements of fuzzy sets and fuzzy decision matrix are described in Table 4-29.

Table 4- 29 The fuzzy decision matrix of Airport SMS elements

Elements	TPE	TSA	KHH
e_{11}	(4.882, 6.882, 8.294)	(4.412, 6.412, 8.294)	(4.412, 6.412, 8.176)
e_{12}	(4.412, 6.412, 8.059)	(4.177, 6.177, 7.941)	(4.294, 6.294, 7.941)
e_{13}	(4.882, 6.882, 8.529)	(4.882, 6.882, 8.647)	(4.882, 6.882, 8.529)
e_{14}	(4.412, 6.412, 8.177)	(3.941, 5.941, 7.824)	(3.941, 5.941, 7.824)
e_{15}	(5.235, 7.235, 8.647)	(4.177, 6.177, 7.941)	(4.177, 6.177, 7.941)
e_{21}	(3.941, 5.941, 7.471)	(4.059, 6.059, 7.824)	(3.941, 5.941, 7.941)
e_{22}	(4.412, 6.412, 8.059)	(4.412, 6.412, 8.059)	(4.647, 6.647, 8.294)
e_{23}	(3.706, 5.706, 7.353)	(3.353, 5.353, 7.000)	(3.353, 5.353, 7.000)
e_{24}	(2.765, 4.765, 6.529)	(2.647, 4.647, 6.412)	(2.765, 4.765, 6.529)
e_{31}	(3.588, 5.588, 7.353)	(3.471, 5.471, 7.235)	(3.000, 5.000, 7.000)
e_{32}	(3.471, 5.471, 7.118)	(3.941, 5.941 7.706)	(3.471, 5.471, 7.235)
e_{33}	(2.294, 4.294, 6.294)	(3.000, 4.882, 6.882)	(2.529, 4.412, 6.412)
e_{34}	(3.235, 5.235, 6.882)	(3.235, 5.235, 7.000)	(2.412, 4.412, 6.412)
e_{41}	(3.588, 5.588, 7.588)	(3.118, 5.118, 7.118)	(2.529, 4.529, 6.529)
e_{42}	(3.941, 5.824, 7.588)	(3.588, 5.588, 7.353)	(3.588, 5.588, 7.353)
e_{43}	(3.941, 5.824, 7.824)	(3.471, 5.471, 7.471)	(3.706, 5.706, 7.706)
e_{44}	(3.750, 5.750, 7.625)	(3.500, 5.500, 7.500)	(3.125, 5.125, 7.125)

Step 2: Construct the weighted fuzzy decision matrix

The fuzzy weighted matrix (Table 4-30) is obtained by multiplying the triangular sets under e_{ij} (Table 4-29) by the corresponding limiting weight in the limiting supermatrix (Table 4-27).

Table 4- 30 The fuzzy weighted matrix of Airport SMS elements

Elements	TPE			TSA			KHH		
e_{11}	(0.520,	0.733,	0.884)	(0.470,	0.683,	0.884)	(0.470,	0.683,	0.871)
e_{12}	(0.223,	0.324,	0.407)	(0.211,	0.312,	0.401)	(0.217,	0.401,	0.397)
e_{13}	(0.264,	0.372,	0.460)	(0.264,	0.372,	0.467)	(0.264,	0.372,	0.460)
e_{14}	(0.127,	0.184,	0.235)	(0.113,	0.171,	0.225)	(0.113,	0.171,	0.225)
e_{15}	(0.151,	0.208,	0.249)	(0.120	0.178,	0.228)	(0.120,	0.178,	0.228)
e_{21}	(0.503,	0.758	0.953)	(0.518,	0.773,	0.998)	(0.503,	0.758,	1.013)
e_{22}	(0.282,	0.409,	0.514)	(0.282,	0.409,	0.514)	(0.297,	0.424,	0.529)
e_{23}	(0.237,	0.364,	0.469)	(0.214,	0.342,	0.447)	(0.214,	0.342,	0.447)
e_{24}	(0.244,	0.421,	0.577)	(0.234,	0.411,	0.567)	(0.244,	0.421,	0.577)
e_{31}	(0.244,	0.379,	0.499)	(0.236,	0.371,	0.491)	(0.204,	0.339,	0.475)
e_{32}	(0.079,	0.124	0.162)	(0.090,	0.135,	0.175)	(0.079,	0.124,	0.164)
e_{33}	(0.073,	0.137,	0.201)	(0.096,	0.156,	0.220)	(0.081,	0.141,	0.205)
e_{34}	(0.082,	0.133,	0.175)	(0.082,	0.133,	0.178)	(0.061,	0.112,	0.163)
e_{41}	(0.204,	0.317,	0.431)	(0.177,	0.291,	0.404)	(0.144,	0.257,	0.371)
e_{42}	(0.267,	0.395,	0.515)	(0.244,	0.379,	0.499)	(0.244,	0.379,	0.499)
e_{43}	(0.224,	0.331,	0.444)	(0.197,	0.311,	0.424)	(0.210,	0.324,	0.438)
e_{44}	(0.127,	0.195,	0.259)	(0.119,	0.187,	0.255)	(0.106,	0.174,	0.242)

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Step 3: Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

Before FPIS and FNIS are determined of this step, the defuzzification is to use in identifies the best fuzzy sets and the worst fuzzy set among the airport SMS elements respectively. This study utilizes the method for Center of Gravity Defuzzification (CGD) (Yager, 1980), the average of the numbers in a fuzzy set is calculated by using the Eq. (4-12).

Step 4: Calculate the distance of each initial element to Positive ideal solution (FPIS) and Negative ideal solutions (FNIS)

Based on the defuzzification in Table 4-31, this study identifies the best and the worst value, and then the FPIS and FNIS fuzzy set are defined as Eq. (4-13) and (4-14) (see Table 3-32). According to the FPIS and FNIS fuzzy set of three airport SMS elements, the distances of FPIS (d_i^*) and FNIS (d_i^-) are calculated by using Eq. (4-15) and (4-16) (see Table 4-32), and the sum of FPIS distances and FNIS are also shown in the bottom of Table 4-33.

Table 4- 31 The defuzzification value of the airport SMS elements

Elements	TPE	TSA	KHH
e_{11}	0.713*	0.679	0.675⁻
e_{12}	0.318	0.308⁻	0.338*
e_{13}	0.365⁻	0.367*	0.365⁻
e_{14}	0.182*	0.170⁻	0.170⁻
e_{15}	0.202*	0.175⁻	0.175⁻
e_{21}	0.738⁻	0.763*	0.753
e_{22}	0.402⁻	0.402⁻	0.417*
e_{23}	0.357*	0.334⁻	0.334⁻
e_{24}	0.414*	0.404⁻	0.414*
e_{31}	0.374*	0.366*	0.339⁻
e_{32}	0.122⁻	0.133*	0.122⁻
e_{33}	0.137⁻	0.157*	0.142
e_{34}	0.130	0.131*	0.112⁻
e_{41}	0.317*	0.291	0.257⁻
e_{42}	0.392*	0.374⁻	0.374⁻
e_{43}	0.333*	0.311⁻	0.324
e_{44}	0.194*	0.187	0.174⁻

Note: * is the best defuzzification values and ⁻ is the worst defuzzification values.

Table 4- 32 The FPIS and FNIS of airport SMS elements

Elements	**TPE**	**TSA**	**KHH**
e_{11}	(0.520, 0.733, 0.884) *	(0.470, 0.683, 0.884)	(0.470, 0.683, 0.871) $^{-}$
e_{12}	(0.223, 0.324, 0.407)	(0.211, 0.312, 0.401) $^{-}$	(0.217, 0.401, 0.397) *
e_{13}	(0.264, 0.372, 0.460) $^{-}$	(0.264, 0.372, 0.467) *	(0.264, 0.372, 0.460) $^{-}$
e_{14}	(0.127, 0.184, 0.235) *	(0.113, 0.171, 0.225) $^{-}$	(0.113, 0.171, 0.225) $^{-}$
e_{15}	(0.151, 0.208, 0.249) *	(0.120, 0.178, 0.228) $^{-}$	(0.120, 0.178, 0.228) $^{-}$
e_{21}	(0.503, 0.758, 0.953) $^{-}$	(0.518, 0.773, 0.998) *	(0.503, 0.758, 1.013)
e_{22}	(0.282, 0.409, 0.514) $^{-}$	(0.282, 0.409, 0.514) $^{-}$	(0.297, 0.424, 0.529) *
e_{23}	(0.237, 0.364, 0.469) *	(0.214, 0.342, 0.447) $^{-}$	(0.214, 0.342, 0.447) $^{-}$
e_{24}	(0.244, 0.421, 0.577) *	(0.234, 0.411, 0.567) $^{-}$	(0.244, 0.421, 0.577)
e_{31}	(0.244, 0.379, 0.499) *	(0.236, 0.371, 0.491)	(0.204, 0.339, 0.475) $^{-}$
e_{32}	(0.079, 0.124, 0.162) $^{-}$	(0.090, 0.135, 0.175) *	(0.079, 0.124, 0.164) $^{-}$
e_{33}	(0.073, 0.137, 0.201)	(0.096, 0.156, 0.220) *	(0.081, 0.141, 0.205) $^{-}$
e_{34}	(0.082, 0.133, 0.175)	(0.082, 0.133, 0.178) *	(0.061, 0.112, 0.163) $^{-}$
e_{41}	(0.204, 0.317, 0.431) *	(0.177, 0.291, 0.404)	(0.144, 0.257, 0.371) $^{-}$
e_{42}	(0.267, 0.395, 0.515) *	(0.244, 0.379, 0.499) $^{-}$	(0.244, 0.379, 0.499) $^{-}$
e_{43}	(0.224, 0.331, 0.444) *	(0.197, 0.311, 0.424) $^{-}$	(0.210, 0.324, 0.438)
e_{44}	(0.127, 0.195, 0.259) *	(0.119, 0.187, 0.255)	(0.106, 0.174, 0.242) $^{-}$

Note: * is FPIS fuzzy set and $^{-}$ is FNIS fuzzy set.,

Step 5: Obtain the Closeness coefficient (CC) and rank the order of airport SMS elements

This study refers the Eq. (4-19) to obtain the CC value via calculation of sum of FPIS (d_i^*) distances and FNIS (d_i^-) (see Table 4-33). Based on the CC value to explain the distance of airport SMS performance is apart from the FPIS or FNIS, if the CC value is high then the distance is closed FPIS, and the performance is good, and vice versa. In this study, the ranks of airport SMS overall elements performance evaluation by CC value are TPE, KHH and TSA (see Table 4-34). By the viewpoints of three grouping areas, and the results of the fuzzy TOPSIS processes from Steps 1 to 5, this study provides the weighted matrix, defuzzification, the distances of FPIS and FNIS for each group listed in Table 4-35 to Table 4-44. By grouping assessment in this study, government and academic area assessed the rankings of three airport SMS performance which are the same, and the ranking from the first to last are TPE, KHH and TSA. In airline industries' view, the three airport SMS performance ranking from top to low is TSA, TPE and KHH (see Table 4-44).

Table 4- 33 The distances of FPIS and FNIS of airport SMS elements

[a] $d(\tilde{v}_{ij},\tilde{v}_j^*)$	Airports			[a] $d(\tilde{v}_{ij},\tilde{v}_j^-)$	Airports		
Elements	**TPE**	**TSA**	**KHH**	**Elements**	**TPE**	**TSA**	**KHH**
e_{11}	0.0000	0.0409	0.0416	e_{11}	0.0416	0.0073	0.0000
e_{12}	0.0450	0.0515	0.0000	e_{12}	0.0103	0.0000	0.0515
e_{13}	0.0037	0.0000	0.0037	e_{13}	0.0000	0.0037	0.0000
e_{14}	0.0000	0.0125	0.0125	e_{14}	0.0125	0.0000	0.0000
e_{15}	0.0000	0.0274	0.0274	e_{15}	0.0274	0.0000	0.0000
e_{21}	0.0287	0.0000	0.0150	e_{21}	0.0000	0.0287	0.0346
e_{22}	0.0150	0.0150	0.0000	e_{22}	0.0000	0.0000	0.0150
e_{23}	0.0000	0.0226	0.0226	e_{23}	0.0226	0.0000	0.0000
e_{24}	0.0000	0.0104	0.0000	e_{24}	0.0104	0.0000	0.0104
e_{31}	0.0000	0.0080	0.0354	e_{31}	0.0354	0.0276	0.0000
e_{32}	0.0117	0.0000	0.0107	e_{32}	0.0016	0.0107	0.0000
e_{33}	0.0201	0.0000	0.0150	e_{33}	0.0000	0.0201	0.0053
e_{34}	0.0000	0.0017	0.0184	e_{34}	0.0184	0.0191	0.0000
e_{41}	0.0000	0.0267	0.0601	e_{41}	0.0601	0.0334	0.0000
e_{42}	0.0000	0.0190	0.0190	e_{42}	0.0190	0.0000	0.0000
e_{43}	0.0000	0.0225	0.0094	e_{43}	0.0225	0.0000	0.0134
e_{44}	0.0000	0.0074	0.0199	e_{44}	0.0199	0.0127	0.0000
[b] d_i^*	0.1242	0.2655	0.3107	[b] d_i^-	0.3015	0.1635	0.1303

[a] $d(\tilde{v}_{ij},\tilde{v}_j^*)$ is the distance between airport fuzzy set and FPIS, and $d(\tilde{v}_{ij},\tilde{v}_j^-)$ is the distance between airport fuzzy set and FNIS.

[b] d_i^* is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^*)$, and d_i^- is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^-)$.

Table 4- 34 The ranking of airport SMS elements performance evaluation by overall assessment

Airport	**TPE**	**KHH**	**TSA**
CC[1]	0.7082	0.3810	0.2954
Rank	1	2	3

Note: Closeness coefficient (CC)

A. By airline industry group viewpoint

Table 4- 35 The fuzzy weighted matrix of Airport SMS elements by airline industry group

Elements	TPE	KHH	TSA
e_{11}	(0.490, 0.703, 0.831)	(0.490, 0.703, 0.874)	(0.533, 0.746, 0.874)
e_{12}	(0.151, 0.252, 0.353)	(0.172, 0.273, 0.373)	(0.172, 0.273, 0.373)
e_{13}	(0.227, 0.335, 0.443)	(0.227, 0.335, 0.443)	(0.205, 0.313, 0.421)
e_{14}	(0.109, 0.167, 0.224)	(0.086, 0.144, 0.201)	(0.086, 0.144, 0.201)
e_{15}	(0.132, 0.190, 0.247)	(0.109, 0.167, 0.224)	(0.098, 0.155 0.224)
e_{21}	(0.332, 0.587, 0.842)	(0.383, 0.638, 0.893)	(0.434, 0.689, 0.944)
e_{22}	(0.217, 0.345, 0.472)	(0.191, 0.319, 0.447)	(0.217, 0.345, 0.472)
e_{23}	(0.194, 0.371, 0.548)	(0.194, 0.371, 0.548)	(0.230, 0.407, 0.583)
e_{24}	(0.194, 0.371, 0.548)	(0.194, 0.371, 0.548)	(0.230, 0.407, 0.583)
e_{31}	(0.122, 0.258, 0.394)	(0.122, 0.258, 0.394)	(0.122 0.258, 0.394)
e_{32}	(0.032, 0.077, 0.123)	(0.050, 0.095, 0.141)	(0.041, 0.086, 0.132)
e_{33}	(0.045, 0.109, 0.173)	(0.045, 0.109, 0.173)	(0.045, 0.109, 0.173)
e_{34}	(0.056, 0.107, 0.158)	(0.066, 0.117, 0.168)	(0.056, 0.107, 0.158)
e_{41}	(0.170, 0.284, 0.397)	(0.170, 0.284, 0.397)	(0.125, 0.238, 0.352)
e_{42}	(0.176, 0.285, 0.421)	(0.122, 0.258, 0.394)	(0.122, 0.258, 0.394)
e_{43}	(0.193, 0.284, 0.397)	(0.170, 0.284, 0.397)	(0.216, 0.329, 0.443)
e_{44}	(0.075, 0.143, 0.210)	(0.088, 0.156, 0.224)	(0.088, 0.156, 0.224)

Table 4- 36 The defuzzification value of the airport SMS elements by airline industry group

Elements	TPE	KHH	TSA
e_{11}	0.675	0.689	0.718
e_{12}	0.252	0.273	0.273
e_{13}	0.335	0.335	0.313
e_{14}	0.167	0.144	0.144
e_{15}	0.190	0.167	0.159
e_{21}	0.587	0.638	0.689
e_{22}	0.345	0.319	0.345
e_{23}	0.371	0.371	0.407
e_{24}	0.371	0.371	0.407
e_{31}	0.258	0.258	0.258
e_{32}	0.077	0.095	0.086
e_{33}	0.109	0.109	0.109
e_{34}	0.107	0.117	0.107
e_{41}	0.284	0.284	0.238
e_{42}	0.294	0.258	0.258
e_{43}	0.291	0.284	0.329
e_{44}	0.142	0.156	0.156

Note: * is the best defuzzification values and $^{-}$ is the worst defuzzification values.

Table 4- 37 The distances of FPIS and FNIS by airline industry group

$d(\tilde{v}_{ij},\tilde{v}_j^*)$ [a]	Airports			$d(\tilde{v}_{ij},\tilde{v}_j^*)$ [a]	Airports		
Elements	TPE	KHH	TSA	Elements	TPE	KHH	TSA
e_{11}	0.0426	0.0348	0.0000	e_{11}	0.0246	0.0246	0.0426
e_{12}	0.0202	0.0000	0.0000	e_{12}	0.0000	0.0202	0.0202
e_{13}	0.0000	0.0000	0.0216	e_{13}	0.0216	0.0216	0.0000
e_{14}	0.0000	0.0230	0.0230	e_{14}	0.0230	0.0000	0.0000
e_{15}	0.0000	0.0230	0.0311	e_{15}	0.0311	0.0094	0.0000
e_{21}	0.1021	0.0510	0.0000	e_{21}	0.0000	0.0510	0.1021
e_{22}	0.0000	0.0256	0.0000	e_{22}	0.0256	0.0000	0.0256
e_{23}	0.0354	0.0354	0.0000	e_{23}	0.0000	0.0000	0.0354
e_{24}	0.0354	0.0354	0.0000	e_{24}	0.0000	0.0000	0.0354
e_{31}	0.0000	0.0000	0.0000	e_{31}	0.0000	0.0000	0.0000
e_{32}	0.0182	0.0000	0.0091	e_{32}	0.0000	0.0182	0.0091
e_{33}	0.0000	0.0000	0.0000	e_{33}	0.0000	0.0000	0.0000
e_{34}	0.0102	0.0000	0.0102	e_{34}	0.0000	0.0102	0.0000
e_{41}	0.0000	0.0000	0.0454	e_{41}	0.0454	0.0454	0.0000
e_{42}	0.0000	0.0384	0.0384	e_{42}	0.0384	0.0000	0.0000
e_{43}	0.0394	0.0454	0.0000	e_{43}	0.0131	0.0000	0.0454
e_{44}	0.0136	0.0000	0.0000	e_{44}	0.0000	0.0136	0.0136
d_i^* [b]	0.3170	0.3120	0.1788	d_i^- [b]	0.2228	0.2142	0.3293

[a] $d(\tilde{v}_{ij},\tilde{v}_j^*)$ is the distance between airport fuzzy set and FPIS, and $d(\tilde{v}_{ij},\tilde{v}_j^-)$ is the distance between airport fuzzy set and FNIS.

[b] d_i^* is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^*)$, and d_i^- is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^-)$.

B. By government group viewpoint

Table 4- 38 The fuzzy weighted matrix of elements by government group assessment

Elements	TPE	KHH	TSA
e_{11}	(0.502, 0.716, 0.898)	(0.472, 0.685, 0.898)	(0.472, 0.685, 0.898)
e_{12}	(0.252, 0.353, 0.425)	(0.252, 0.353, 0.425)	(0.267, 0.368, 0.425)
e_{13}	(0.270, 0.378, 0.470)	(0.285, 0.393, 0.486)	(0.301, 0.409, 0.486)
e_{14}	(0.136, 0.193, 0.242)	(0.136, 0.193, 0.242)	(0.136, 0.193, 0.242)
e_{15}	(0.177, 0.234, 0.259)	(0.136, 0.193, 0.234)	(0.144, 0.201, 0.242)
e_{21}	(0.602, 0.857, 1.003)	(0.565, 0.820, 1.003)	(0.492, 0.747, 1.003)
e_{22}	(0.319, 0.447, 0.538)	(0.337, 0.465, 0.538)	(0.355, 0.483, 0.556)
e_{23}	(0.417, 0.593, 0.694)	(0.391, 0.568, 0.669)	(0.366, 0.543, 0.644)
e_{24}	(0.265, 0.442, 0.568)	(0.265, 0.442, 0.568)	(0.265, 0.442, 0.568)
e_{31}	(0.281, 0.417, 0.514)	(0.281, 0.417, 0.514)	(0.223, 0.359, 0.494)
e_{32}	(0.107, 0.152, 0.185)	(0.120, 0.165, 0.198)	(0.107, 0.152, 0.185)
e_{33}	(0.078, 0.142, 0.205)	(0.123, 0.178, 0.242)	(0.105, 0.160, 0.224)
e_{34}	(0.091, 0.142, 0.178)	(0.091, 0.142, 0.178)	(0.055, 0.105, 0.156)
e_{41}	(0.187, 0.300, 0.414)	(0.203, 0.316, 0.430)	(0.154, 0.268, 0.381)
e_{42}	(0.339, 0.475, 0.572)	(0.320, 0.456, 0.553)	(0.339, 0.475, 0.572)
e_{43}	(0.219, 0.333, 0.446)	(0.219, 0.333, 0.446)	(0.219, 0.333, 0.446)
e_{44}	(0.075, 0.142, 0.210)	(0.088, 0.156, 0.224)	(0.088, 0.156, 0.224)

Table 4- 39 The defuzzification value of elements by government group assessment

Elements	TPE	KHH	TSA
e_{11}	0.705	0.685	0.685
e_{12}	0.344	0.344	0.353
e_{13}	0.373	0.388	0.398
e_{14}	0.190	0.190	0.190
e_{15}	0.223	0.188	0.196
e_{21}	0.820	0.796	0.747
e_{22}	0.434	0.447	0.465
e_{23}	0.568	0.543	0.518
e_{24}	0.425	0.425	0.425
e_{31}	0.404	0.404	0.359
e_{32}	0.148	0.161	0.148
e_{33}	0.142	0.181	0.163
e_{34}	0.137	0.137	0.105
e_{41}	0.300	0.316	0.268
e_{42}	0.462	0.443	0.462
e_{43}	0.333	0.333	0.333
e_{44}	0.142	0.156	0.156

Note: * is the best defuzzification values and ¯ is the worst defuzzification values.

Table 4- 40 The distances of FPIS and FNIS by government group assessment

$d(\tilde{v}_{ij},\tilde{v}_j^*)$ [a]	Airports			$d(\tilde{v}_{ij},\tilde{v}_j^*)$ [a]	Airports		
Elements	TPE	KHH	TSA	Elements	TPE	KHH	TSA
e_{11}	0.0000	0.0249	0.0249	e_{11}	0.0249	0.0000	0.0000
e_{12}	0.0118	0.0118	0.0000	e_{12}	0.0000	0.0000	0.0118
e_{13}	0.0267	0.0126	0.0000	e_{13}	0.0000	0.0154	0.0267
e_{14}	0.0000	0.0000	0.0000	e_{14}	0.0000	0.0000	0.0000
e_{15}	0.0000	0.0364	0.0285	e_{15}	0.0364	0.0000	0.0082
e_{21}	0.0000	0.0298	0.0893	e_{21}	0.0893	0.0595	0.0000
e_{22}	0.0316	0.0182	0.0105	e_{22}	0.0000	0.0149	0.0316
e_{23}	0.0000	0.0253	0.0505	e_{23}	0.0505	0.0253	0.0000
e_{24}	0.0000	0.0000	0.0000	e_{24}	0.0000	0.0000	0.0000
e_{31}	0.0000	0.0000	0.0488	e_{31}	0.0488	0.0488	0.0000
e_{32}	0.0130	0.0000	0.0130	e_{32}	0.0000	0.0130	0.0000
e_{33}	0.0398	0.0000	0.0183	e_{33}	0.0000	0.0398	0.0217
e_{34}	0.0000	0.0000	0.0322	e_{34}	0.0322	0.0322	0.0000
e_{41}	0.0162	0.0000	0.0487	e_{41}	0.0324	0.0487	0.0000
e_{42}	0.0000	0.0194	0.0000	e_{42}	0.0194	0.0000	0.0194
e_{43}	0.0000	0.0000	0.0000	e_{43}	0.0000	0.0000	0.0000
e_{44}	0.0136	0.0000	0.0000	e_{44}	0.0000	0.0136	0.0136
d_i^* [b]	0.1526	0.1783	0.3646	d_i^- [b]	0.3340	0.3112	0.1330

[a] $d(\tilde{v}_{ij},\tilde{v}_j^*)$ is the distance between airport fuzzy set and FPIS, and $d(\tilde{v}_{ij},\tilde{v}_j^-)$ is the distance between airport fuzzy set and FNIS.

[b] d_i^* is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^*)$, and d_i^- is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^-)$.

C. By academy group viewpoint:

Table 4- 41 The fuzzy weighted matrix of elements by academic group assessment

Elements	TPE	KHH	TSA
e_{11}	(0.575, 0.789, 0.916)	(0.448, 0.661, 0.874)	(0.405, 0.618, 0.831)
e_{12}	(0.252, 0.353, 0.434)	(0.192, 0.293, 0.394)	(0.192, 0.293, 0.394)
e_{13}	(0.291, 0.399, 0.464)	(0.270, 0.378, 0.464)	(0.270, 0.378, 0.464)
e_{14}	(0.132, 0.190, 0.236)	(0.109, 0.167, 0.224)	(0.109, 0.167, 0.224)
e_{15}	(0.132, 0.190, 0.236)	(0.109, 0.167, 0.224)	(0.109, 0.167, 0.224)
e_{21}	(0.536, 0.791, 0.995)	(0.587, 0.842, 1.097)	(0.587, 0.842, 1.097)
e_{22}	(0.294, 0.421, 0.523)	(0.294, 0.421, 0.549)	(0.294, 0.421, 0.549)
e_{23}	(0.336, 0.513, 0.689)	(0.265, 0.442, 0.619)	(0.265, 0.442, 0.619)
e_{24}	(0.265, 0.442, 0.619)	(0.230, 0.407, 0.583)	(0.230, 0.407, 0.583)
e_{31}	(0.312, 0.448, 0.584)	(0.285, 0.421, 0.557)	(0.258, 0.394, 0.529)
e_{32}	(0.086, 0.132, 0.168)	(0.086, 0.132, 0.177)	(0.077, 0.123, 0.168)
e_{33}	(0.096, 0.160, 0.224)	(0.109, 0.173, 0.236)	(0.083, 0.147, 0.211)
e_{34}	(0.097, 0.148, 0.188)	(0.087, 0.137, 0.188)	(0.076, 0.127, 0.178)
e_{41}	(0.261, 0.375, 0.488)	(0.148, 0.261, 0.375)	(0.148, 0.261, 0.375)
e_{42}	(0.258, 0.394, 0.529)	(0.258, 0.394, 0.529)	(0.231, 0.366, 0.502)
e_{43}	(0.261, 0.375, 0.488)	(0.193, 0.307, 0.420)	(0.193, 0.307, 0.420)
e_{44}	(0.156, 0.224, 0.278)	(0.129, 0.197, 0.265)	(0.102, 0.170, 0.237)

Table 4- 42 The defuzzification value of elements by academic group assessment

Elements	TPE	KHH	TSA
e_{11}	0.760	0.661	0.618
e_{12}	0.347	0.293	0.293
e_{13}	0.385	0.371	0.371
e_{14}	0.186	0.167	0.167
e_{15}	0.186	0.167	0.167
e_{21}	0.774	0.842	0.842
e_{22}	0.413	0.421	0.421
e_{23}	0.513	0.442	0.442
e_{24}	0.442	0.407	0.407
e_{31}	0.448	0.421	0.394
e_{32}	0.129	0.132	0.123
e_{33}	0.160	0.173	0.147
e_{34}	0.144	0.137	0.127
e_{41}	0.375	0.261	0.261
e_{42}	0.394	0.394	0.366
e_{43}	0.375	0.307	0.307
e_{44}	0.219	0.197	0.170

Note: * is the best defuzzification values and ⁻ is the worst defuzzification values.

Table 4- 43 Overall components Performance ranking by academic group assessment

$d(\tilde{v}_{ij},\tilde{v}_j^*)$ [a]	Airports			$d(\tilde{v}_{ij},\tilde{v}_j^-)$ [a]	Airports		
Elements	TPE	KHH	TSA	Elements	TPE	KHH	TSA
e_{11}	0.0000	0.1073	0.1477	e_{11}	0.1477	0.0426	0.0000
e_{12}	0.0000	0.0547	0.0547	e_{12}	0.0547	0.0000	0.0000
e_{13}	0.0000	0.0176	0.0176	e_{13}	0.0176	0.0000	0.0000
e_{14}	0.0000	0.0199	0.0199	e_{14}	0.0199	0.0000	0.0000
e_{15}	0.0000	0.0199	0.0199	e_{15}	0.0199	0.0000	0.0000
e_{21}	0.0722	0.0000	0.0000	e_{21}	0.0000	0.0722	0.0722
e_{22}	0.0147	0.0000	0.0000	e_{22}	0.0000	0.0147	0.0147
e_{23}	0.0000	0.0707	0.0707	e_{23}	0.0707	0.0000	0.0000
e_{24}	0.0000	0.0354	0.0354	e_{24}	0.0354	0.0000	0.0000
e_{31}	0.0000	0.0271	0.0543	e_{31}	0.0543	0.0271	0.0000
e_{32}	0.0052	0.0000	0.0091	e_{32}	0.0074	0.0091	0.0000
e_{33}	0.0128	0.0000	0.0256	e_{33}	0.0128	0.0256	0.0000
e_{34}	0.0000	0.0083	0.0176	e_{34}	0.0176	0.0102	0.0000
e_{41}	0.0000	0.1135	0.1135	e_{41}	0.1135	0.0000	0.0000
e_{42}	0.0000	0.0000	0.0271	e_{42}	0.0271	0.0271	0.0000
e_{43}	0.0000	0.0681	0.0681	e_{43}	0.0681	0.0000	0.0000
e_{44}	0.0000	0.0235	0.0502	e_{44}	0.0502	0.0271	0.0000
d_i^* [b]	0.1050	0.5661	0.7314	d_i^- [b]	0.7169	0.2558	0.0869

[a] $d(\tilde{v}_{ij},\tilde{v}_j^*)$ is the distance between airport fuzzy set and FPIS, and $d(\tilde{v}_{ij},\tilde{v}_j^-)$ is the distance between airport fuzzy set and FNIS.

[b] d_i^* is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^*)$, and d_i^- is the sum of distance for $d(\tilde{v}_{ij},\tilde{v}_j^-)$.

By summarizing the above calculations on the individual grouping area, the rankings of airport SMS elements performance are given in Table 4-44. Due to Information asymmetry among three areas of experts, those from airline industry have better knowledge on practical operations than the other two groups. The area of airline industries received much more weights in components C_1 and C_2 than components C_3 and C_4 (see Table 4-28). So the rankings of CC values on three airports in Airline industries are TSA, TPE and KHH (see Table 4-44).

Table 4- 44 The ranking of airport SMS elements performance by grouping assessment

Group	**Airline industries**			**Governments area**			**Academic area**		
Airport	**TPE**	**KHH**	**TSA**	**TPE**	**KHH**	**TSA**	**TPE**	**KHH**	**TSA**
CC	0.4128	0.4071	0.6481	0.6863	0.6357	0.2672	0.8723	0.3112	0.1062
Rank	2	3	1	1	2	3	1	2	3

Note: Closeness coefficient (CC)

Based on four components of airport SMS, this study summaries the specific result of different components by the overall assessment (see Table 4-45). Under the component 1, the airport SMS rank of the first one is TPE with 0.9873 CC value; under component 2, the top of performance ranking is TSA with 0.6155 CC value; KHH is the first rank under component 3 performance evaluation with 1.0000 CC value; TPE has the highest CC value in component 4 performance evaluation ranking.

Table 4- 45 The specific ranking of airport SMS components

Components/CC value rank	**TPE**	**KHH**	**TSA**
$\boldsymbol{C}_1$: *Safety policy and objectives*	0.9873	0.9417	0.9576
Rank	1	3	2
$\boldsymbol{C}_2$: *Safety risk management*	0.4293	0.3749	0.6155
Rank	2	3	1
$\boldsymbol{C}_3$: *Safety assurance*	0.6056	1.0000	0.5377
Rank	2	1	3
$\boldsymbol{C}_4$: *Safety promotion*	1.0000	0.3287	0.1572
Rank	1	2	3

In order to compare the performance with previous method (that is, fuzzy TOPSIS) this study used the usual weighted average method to rank the overall evaluation on the components and individual elements under each component of airport SMS separately according to the fuzzy triangular data provided by expert's judgments.

Under the component C_1 (*Safety policy and objectives*), TPE received the highest ranking in *Management commitment and responsibility* ($\boldsymbol{e}_{11}$), *Safety accountability* ($\boldsymbol{e}_{12}$), *Coordination of emergency response planning* ($\boldsymbol{e}_{14}$) and *SMS documentation* ($\boldsymbol{e}_{15}$) with the average performance value of 0.7125, 0.3176, 0.1821, and 0.2024, respectively. The performance rankings in *Appointment of key safety personnel* ($\boldsymbol{e}_{13}$) are in order of KHH, TPE and TSA, but they are very close to each other (see Table 4-46). The results reveal that the *Appointment of key safety personnel* are similar between government-owned incorporated and governmental airports. To compare the rankings by weighted average method and fuzzy TOPSIS method under the component C_1, TPE is the top ranking, and KHH is the second rank by weighted average (Table 4-47) and the third rank by fuzzy TOPSIS method (see Table 4-45).

Table 4- 46 The ranking of airport SMS elements under component C_1 by weighted average

Elements under C_1 *Safety policy and objectives* Average rank	**TPE**	**KHH**	**TSA**
$\boldsymbol{e}_{11}$: *Management commitment and responsibility*	0.7125	0.6791	0.6749
Rank	1	2	3
$\boldsymbol{e}_{12}$: *Safety accountability*	0.3176	0.3077	0.3117
Rank	1	3	2
$\boldsymbol{e}_{13}$: *Appointment of key safety personnel*	0.3652	0.3673	0.3652
Rank	2	1	2
$\boldsymbol{e}_{14}$: *Coordination of emergency response planning*	0.1821	0.1697	0.1697
Rank	1	2	2
$\boldsymbol{e}_{15}$: *SMS documentation*	0.2024	0.1753	0.1753
Rank	1	2	2

Table 4- 47 The ranking of airport SMS elements under component C_1 by weighted average

C_1	**TPE**	**KHH**	**TSA**
$\boldsymbol{e}_{11}$	0.7125	0.6791	0.6749
$\boldsymbol{e}_{12}$	0.3176	0.3077	0.3117
$\boldsymbol{e}_{13}$	0.3652	0.3673	0.3652
$\boldsymbol{e}_{14}$	0.1821	0.1697	0.1697
$\boldsymbol{e}_{15}$	0.2024	0.1753	0.1753
Sum	1.7798	1.6991	1.6968
Weighted average	0.3560	0.3398	0.3394
Rank	1	2	3

Under the component C_2 (*Safety risk management*), TPE received the highest ranking in *Safety risk mitigation strategies* (e_{23}), *To implement, track and monitor the safety risk mitigation* ($\boldsymbol{e}_{24}$) with the average performance value of 0.3566 and 0.4142, respectively. KHH has the highest performance in *Hazard identification* (e_{21}) and TSA has the top ranking in *Safety risk assessment system* (e_{22}) and *To implement, track and monitor the safety risk mitigation* (e_{24}). Under this component, the average performance values are close among each element (see Table 4-48). The ranking of elements under component C_2 is the same by both the fuzzy TOPSIS methods and the weighted average (see Table 4-44 and Table 4-49).

Table 4- 48 The ranking of airport SMS elements under component C_2 by weighted average

Elements under C_2: *Safety risk management* Average rank	**TPE**	**KHH**	**TSA**
***e**$_{21}$: Hazard identification*	0.7382	0.7632	0.7582
Rank	3	1	2
***e**$_{22}$: Safety risk assessment system*	0.4016	0.4016	0.4166
Rank	2	2	1
***e**$_{23}$:Safety risk mitigation strategies*	0.3566	0.3340	0.3340
Rank	1	2	2
***e**$_{24}$:To implement, track and monitor the safety risk mitigation*	0.4142	0.4038	0.4142
Rank	1	3	1

Table 4- 49 The ranking of airport SMS elements under component C_2 by weighted average

C2	**TPE**	**KHH**	**TSA**
***e**$_{21}$*	0.7382	0.7632	0.7582
***e**$_{22}$*	0.4016	0.4016	0.4166
***e**$_{23}$*	0.3566	0.334	0.334
***e**$_{24}$*	0.4142	0.4038	0.4142
Sum	1.9106	1.9026	1.923
Weighted average	0.47765	0.47565	0.48075
Rank	2	3	1

Under the component C_3 (*Safety assurance*), the performance of all elements are in the low end. KHH has the highest ranking in all three elements except the *Safety performance monitoring and measurement* (e_{31}) while TPE performed the best in element e_{31} (see Table 4-50). The ranking of elements under component C_3 is the same by both the fuzzy TOPSIS methods and the weighted average (see Table 4-44 and Table 4-51).

Table 4- 50 The ranking of airport SMS elements under component C_3 by weighted average

Elements under C_3: *Safety assurance* Average rank	**TPE**	**KHH**	**TSA**
***e**$_{31}$ Safety performance monitoring and measurement*	0.3740	0.3660	0.3394
Rank	1	2	3
***e**$_{32}$ The management of change*	0.1216	0.1331	0.1225
Rank	3	1	2
***e**$_{33}$ A non-punitive safety reporting system*	0.1372	0.1573	0.1422
Rank	3	1	2
***e**$_{34}$ Continuous improvement of the SMS*	0.1302	0.1312	0.1123
Rank	2	1	3

Table 4- 51 The ranking of airport SMS elements under component C_3 by weighted average

C_3	TPE	KHH	TSA
e_{31}	0.374	0.366	0.3394
e_{32}	0.1216	0.1331	0.1225
e_{33}	0.1372	0.1573	0.1422
e_{34}	0.1302	0.1312	0.1123
Sum	0.763	0.7876	0.7164
Weighted average	0.19075	0.1969	0.1791
Rank	2	1	3

Under the component C_4 (*Safety promotion*), TPE is the best in all four elements. The overall performance values are in the middle range of airport SMS performance (see Table 4-52). The ranking of elements under component C_4 is the same by both the fuzzy TOPSIS and the weighted average methods (see Table 4-44 and Table 4-53). And finally, the rankings of components are the same by two methods (see Table 4-44 and Table 4-54).

Table 4- 52 The ranking of airport SMS elements under component C_4 by weighted average

Elements under C_4: *Safety promotion* Average rank	TPE	KHH	TSA
e_{41} *Safety culture*	0.3172	0.2905	0.2571
Rank	1	2	3
e_{42} *Training and education*	0.3925	0.3739	0.3739
Rank	1	2	2
e_{43} *Safety communication*	0.3328	0.3106	0.3239
Rank	1	3	2
e_{44} *Safety competency and continuous improvement*	0.1937	0.1866	0.1739
Rank	1	2	3

Table 4- 53 The ranking of airport SMS elements under component C_4 by weighted average

C_4	TPE	KHH	TSA
e_{41}	0.3172	0.2905	0.2571
e_{42}	0.3925	0.3739	0.3739
e_{43}	0.3328	0.3106	0.3239
e_{44}	0.1937	0.1866	0.1739
Sum	1.2362	1.1616	1.1288
Weighted average	0.30905	0.2904	0.2822
Rank	1	2	3

Table 4- 54 The ranking of airport SMS components by weighted average

Component	TPE	KHH	TSA
C_1	0.3560	0.3398	0.3394
C_2	0.4777	0.4757	0.4808
C_3	0.1908	0.1969	0.1791
C_4	0.3091	0.2904	0.2822
Sum	1.3334	1.3028	1.2814
Weighted average	0.3334	0.3257	0.3204
Rank	1	2	3

Based on the result of airport SMS performance rank, TPE has the top one ranking than KHH and TSA in overall assessment and grouping assessment by governments and academic areas. Refer to Table 4-45 and Table 4-54, this research specifically points out that some safety operations in components and elements are insufficient to assure the airport SMS implementation. According to TPE Aerodrome manual (TIAC, 2012) for SMS gap analysis:

1. Under the Component C_2 (*Safety risk management*), the element e_{21} of Hazard identification is insufficient based on a combination of reactive, proactive and predictive method of safety data collection.
2. Under the Component C_3 (*Safety assurance*), the safety performances of element e_{31} for Safety performance monitoring and measurement, element e_{32} for The management of change and element e_{33} for *A non-punitive safety report system* are insufficient.

According to KHH and TSA SMS manuals (CAA, 2012a) (CAA, 2012a) for SMS gap analysis:

1. Under the Component C_1 (*Safety policy and objectives*), the elements e_{12} of Safety policy and accountabilities is insufficient due to the staffs of KHH and TSA are administrated by CAA in Taiwan.
2. Under the Component C_2 (*Safety risk management*), the element e_{21} of Hazard identification which is insufficient based on a combination of reactive, proactive and predictive method of safety data collection.
3. Under the Component C_3 (*Safety assurance*), the element e_{31} for Safety performance monitoring and measurement and element e_{34} for *Continuous improvement of the SMS* are insufficient.

4.6.3 Interview and summary

In order to understand the actual operations of airport SMS operation and to verify the result of research in Part two, this study interviewed the top SMS managers at TPE, KHH and TSA international airports during March 6 to 8, 2013. The top SMS managers interviewed have had more than 20 years of working experience and the full interviews were carried out in Chinese which are illustrated in Appendix 6. Based on the specific SMS components, the interviews and discussions are summarized in the following:

1. ***C_1*: *Safety policy and objectives*** (Overall ranking: TPE, TSA and KHH)

    Safety policy provides the foundation for SMS (FAA, 2012). Stolzer et al. (2008) pointed out that the senior management plays an important role on performing SMS efficiently in devoting attention, time and resources. Refer to the Table 4-33 and 4-34, TPE is the top ranked airport except e_{13} (*Appointment of key safety personal*) under the C_1 (*Safety policy and objectives*). It represents that the performance of e_{13} is closely related to feature of government-owned incorporated airport (TPE), governmental and civil-military airports (KHH and TSA).

    According to the results of the interviews from these three airports, not only TSA and KHH, but also TPE's new staffs of flight operation division have the SMS training in CAA's Aviation Training Institute. And the seed training of KHH and TPE for safety management course is to be held in Singapore Aviation Academy regularly. Under the element e_{13} (*Appointment of key safety personal*), the first ranking is KHH while TPE and TSA have the same rank at the second. The result is in compliance with the actual expert's e_{13} performance evaluation.

2. ***C_2*: *Safety risk management*** (Overall ranking: TSA, TPE and KHH)

    It was suggested by ICAO (2009) that airport safety administrators shall be based on a combination of reactive, proactive and predictive methods of safety data collection in identifying areas of hazard. In this study, three all airports all follow the ICAO's suggestions to conduct risk management, which is not only established in the SMS manual but also in regular daily operations. Part two research observes that when the airport constructions are proceeding in surface and terminal areas (such as runway repairing or terminal constructing), more risk management is needed.

    Based on the interview of TPE, TPE runway inspections (ICAO, 1983) are preceded S route twice a day in off-peak segment by Fight Operation Division and Air Traffic Control (ATC) during the runway repairing period from June 2013 to February 2014. As is known that the damages of TPE runway is related to the performance of SMS in risk management and it is also connected to the airport service quality and interaction of stakeholder. Besides, regarding the airport service of movement announcement, TPE Operation Control Center (OCC) integrates the information of airside and landside to the related divisions to quickly respond in airport system.

TSA is the top ranking in C_2 performance which results in quick response to the requirements for the airport users and provides stable surface without constructions. KHH SMS group imbeds the safety concepts into the daily work smoothly through attending regular airport SMS committee meeting, pilot meeting, runway safety meeting and apron safety meeting.

3. $\boldsymbol{C}_3$: ***Safety assurance*** (Overall ranking: KHH, TPE and TSA)

Under the component $\boldsymbol{C}_3$, airport SMS staffs shall practice *the management of change* ($\boldsymbol{e}_{32}$) (ICAO, 2009b) and *A non-punitive safety reporting system* ($\boldsymbol{e}_{33}$) (FAA, 2007) and thus KHH gains the top ranking under $\boldsymbol{C}_3$ (*Safety assurance*). Based on the content of the interview, the nature of culture at KHH's SMS practice is "Local Culture" (such as the safety reminding and concerning to each other for all stakeholders in airport) in which the stakeholders are respected and assisted (such as the meeting with pilots per season).

The safety management character of TPE is "The participation of flight safety and security for all citizens"; all stakeholders are the best monitors to watch any risk and to track the movement of improvement. In Particular, with respect to human factor management, TPE uses the safety record of employees to control the approval of working license, and similarly, TSA also does the same way to reduce the events of human factors. In the safety external and internal audit, TPE and KHH follow the airport SMS operations, and TSA practices CAA's inspection operations. Based on the airport SMS implementation for $\boldsymbol{C}_3$ (***Safety assurance***), the result is consistent to the overall ranking.

4. $\boldsymbol{C}_4$: ***Safety promotion*** (Overall ranking: TPE, KHH and TSA)

An organization should continually promote safety as a core value with practices, safety education and safety culture (Stolzer et al., 2008). For this reason, the results of performance evaluation reflect the airport sustainable operations, particularly in safety education for seed instructors training: TPE and KHH participate a routine training program for seed instructors held at Singapore's Aviation Academy. And all of flight operational relating to new staffs have SMS course at CAA's Aviation Training Institute. The TSA creates the safety risk notification in the surface driver's license exam, which not only can provide instant SMS notification channels, but also encourage all stakeholders to inform TSA safety office and flight operations center of safety risks.

Under $\boldsymbol{C}_4$ (*Safety promotion*), airport safety culture is the core value for safety improvement, TPE has emphasized the safety responsibility of all citizens; KHH executes the daily duties with local safety culture smoothly and efficiently; the TSA's safety culture is to respond the user's requirements in a fast and timely way.

5. ***Airport SMS performance evaluation*** (Overall ranking: TPE, KHH and TSA)

The constructions of SMS manual at three airports have been completed; TPE and KHH SMS team-works are following the directions of the SMS manual. According to the content of TSA interview, the operations of C_3 (*Safety assurance*) and C_4 (*Safety promotion*) have not yet been implemented, particularly under $\boldsymbol{e}_{31}$ (*Safety performance monitoring and measurement*) requirements, TSA uses the CAA's airport auditing to replace external auditing and self-auditing. Based on the results of overall ranking, the contents of interview confirm the actual practices of three airports.

Further, according to the characteristic of airport, TSA is a both civil and military airport, and they have different surface management systems for CAA and military (for example, A, B and C gaps of military taxiway are different from those of civil in TSA). However, considering the overall SMS performance in aviation industry's viewpoint, TSA has the first ranking because it emphasizes the interaction between stakeholders and airport SMS group. This is because TSA's SMS group has the nature of quick assistance to users in safety culture through flight operational lines.

At last, the overall performance ranking for three airports is consistent with the actual relationship between C_2 (*Safety risk management*), C_3 (*Safety assurance*) and C_4 (*Safety promotion*). Refer to the TSA's third order in overall ranking, even though the TSA has quick response to users and efficient risk management operations, it is weakness of the implementations for C_3 and C_4 operations which affects its ranking in airport SMS performance. Based on the nature of government-owned incorporated, governmental, civil-military airports, a modern airport shall efficiently respond to the requirements in surface and terminal constructions under the dynamic and uncertain situations, and the different properties for airport can affect the implementation of safety policy and safety culture. For example, in TPE SMS performance in C_2 (*Safety risk management*), the more ongoing surface constructions are, the more risk management is needed, not only in human factor management system but also in airport facilities to prevent FOD from entering into the surface.

Chapter 5 Discussions and Conclusions

This chapter is to describe the findings and conclusions of this research, Part one is to derive the most significant ICAO occurrence categories which are related to Part two and to show the importance of airport safety management. Finally, the contributions and further research are also discussed.

5.1 Conclusions of Analysis of an Aircraft Accident Model

The objective of research Part one is to first establish a Poisson probability distribution for the occurrences and to use Poisson regression to explain the relationship between the occurrence rate and the ICAO categories of occurrences for the period from 1985 to 2010 in Taiwan. Then its associated Poisson regression is employed to explain the relationship of occurrence rate, fatality rate, accident rate and serious incident rate, respectively, with the ICAO occurrence categories. Since the number of fatal accidents is generally extremely rare, but when it happens it can cause a huge fatal loss than that of accidents or serious incidents, this study also uses the fatality rate to find the significance of the ICAO categories and then to explain their relation to fatal accidents.

It is well-known that the number of occurrences relative to the total number of departures can be modeled by a binomial or a negative binomial distribution. But, the number of occurrences is very small, a binomial or a negative binomial distribution has a computational difficulty, this study has proved that a Poisson distribution and its regression can serve as an excellent approximation because the Poisson distribution is a limiting distribution of the binomial and negative binomial distributions.

Based on the twenty-six years of aviation data in Taiwan and the Poisson model of the occurrences, this study has found that the ICAO grouping categories Takeoff, Landing, and Ground Operation and Aircraft, and the subcategories Icing, Turbulence Encounter and Other have most significant effects on the occurrences. The subcategories Controlled Flight into/toward Terrain and System/Component Failure or Malfunction (Non- Power plant) have most significant effects on the fatal accidents occurring during the period from 1985 to 2010, and the subcategories Runway Incursion-Vehicle, Aircraft or Person, Ground Collision and Undershoot or Overshoot have most significant effect on the accidents occurring. The Runway Excursion subcategory has the most significant effect on the serious incidents and these related information not only can provide airports to reach SSP safety targets via airport SMS operations but also reduce the Runway Excursion and Ground Collision events (see the shaded overlapping area of Fig.1-1).

5.2 Conclusions of Airport SMS Performance Evaluation

Based on the finding of Part one research, the ICAO grouping categories Takeoff, Landing, and Ground Operation (TLGO) has top one significant effect on the occurrences and the Runway Excursion subcategory has the most significant effect on the serious incidents, both TLGO and RE occurrences often happen at the ground of airports. This result forms a basis for the airport SMS operating elements and provides relevant information to airport safety management operations (see the shaded overlapping area of Fig.1-1). For this reason, the airport safety management is more important for aviation industries, and Part two intents to establish airport SMS components and elements to evaluate international airport SMS performance via reviewing the SMS manuals of ICAO, Taiwan CAA and United State FAA.

The results of research Part two are described by two stage expert questionnaire survey and interviews, in the first stage, this research find the airport SMS weights and weight rankings for components and elements via ANP method. The rankings of components from high to low are: C_2 (*Safety risk management*), C_1 (*Safety policy and objectives*), C_4 (*Safety promotion*) and C_3 (*Safety assurance*). The top five weights of overall ranking for elements are e_{21} (*Hazard identification*), e_{11} (*Management commitment and responsibility*), e_{23} (*Safety risk mitigation strategies*), e_{24} (*To implement, track and monitor the safety risk mitigation*)

Since the weight rankings of SMS components at stage one are different, it is intended to further compare SMS performance of these three airports at stage two via fuzzy TOPSIS method. It has been found that the overall performance rankings are TPE, TSA, and KHH under C_1 (*Safety policy and objectives*); the performance rankings are TSA, TPE, and KHH under C_2 (*Safety risk management*); under C_3 (*Safety assurance*), the performance rankings are KHH, TPE and TSA; and under C_4 (*Safety promotion*), the performance rankings are TPE, KHH and TSA.

It has been found that the overall rankings of airport SMS performance of three international airports are the same as in the order of TPE, KHH and TSA by both the weighted average and the fuzzy TOPSIS methods. By the grouping view under Government and Academic area, respectively, the ranks of SMS performance are identical with rankings from high to low as: TPE, KHH and TSA, which is the exactly same by overall views. From the airline industries' viewpoint, TSA wins the top ranking for SMS performance, and the next two winners are in the order of TPE and KHH. For the purpose to verify the results obtained from questionnaire survey at stage two, this study has also conducted a face-to-face interview with the top SMS managers at these airports following the stage two survey. The major findings of these interviews are illustrated below:

Under C_1 (*Safety policy and objectives*), the performance rankings are TPE, TSA, and KHH. Based on the nature of government-owned incorporated, civil-military and governmental airports, a modern airport shall efficiently respond to the requirements by the stakeholders and different properties for airport can affect the implementation of safety policy and safety culture. Under C_2 (*Safety risk management*) performance evaluation, the more constructions in surface and terminal areas are, the more attentions are needed in risk management under the dynamic and uncertain situations in airport SMS operations. It was found that the components of C_2 (*Safety risk management*), C_3 (*Safety assurance*) and C_4 (*Safety promotion*) are related. According to the interview, TSA has high efficient in C_2 and weak implementations in C_3 and C_4 operations. Under C_3 (*Safety assurance*), the overall performance rankings are in the order of KHH, TPE and TSA. These results are caused by actual practices in external- and self-auditing by SMS operations at TPE and KHH, but TSA uses the CAA's airport auditing which results in different in SMS's safety promotion aspect. For the purpose of keeping sustainable airport operations, it is necessary to promote safety education. Under C_4 (*Safety promotion*), the performance rankings are in order of TPE, KHH and TSA, because TPE and KHH have regular international training programs for seed instructors to improve airport safety management capability.

The findings of this research can provide aviation authorities, airport administrators and airlines companies in Taiwan with a direction for safety risk management and allocation of materials and resources to conduct safety training in order to prevent aviation occurrences from happening. Furthermore, based on the findings of research Part one, the significant sub-categories of Runway Incursion-Vehicle, Aircraft or Person, Ground Collision and Undershoot or Overshoot airport safety data analysis can be the directions and implementation of airport SMS operations.

According to the findings of this research, some suggestions are given as below:

1. To establish the airport SMS performance evaluation system by government administration and to share the safety management experiences from the excellent airport under the dynamic and uncertain situations in airport SMS operations.
2. To share the safety information via the safety events database by CAA authority in Taiwan, and to conduct the safety conference for airports SMS staffs, airlines industries and academic area.
3. For the reason to improve the efficiency of airport SMS, the evaluation scales and reports writing for the implements of risk management component (C_2) should be established, which can contrast with the ICAO Annex 13 – Aircraft accident and incident investigation (ICAO, 2001a) and Doc 9859 – Safety Management Manual.

5.2 Research Contributions

According to the results of the research in Part one and Part two, the contributions of this thesis are described below:

- **Part one: Analysis of an Aircraft Accident Model in Taiwan**

In this Part, the contribution is the first time to use the Poisson probability distribution and Poisson regression successfully to model the occurrences in Taiwan Aviation data because the Poisson distribution is the limiting distribution of the binomial and the negative binomial distributions. The sample of 26 years of aviation occurrence data is appropriate to fit the Poisson regression model; thus, Part one research can be a basis to analyze a similar discrete aviation occurrence data.

The contribution of research is to use the Poisson regression to explain the relationship between the occurrence rate and the ICAO categories of occurrences for the period from 1985 to 2010 in Taiwan. Practically, based on the severity of occurrences in Part one, the occurrences are divided into fatal accidents, accidents and serious incidents, and then apply the Poisson regression to each of them in order to find the true causes in Taiwan air safety history. The finding of the research in Part one is that the Runway Excursion subcategory has the most significant effect on the serious incidents occurring, and this result is consistent with ICAO SSP safety targets for risk reduction.

- **Part two: Conclusions of Airport SMS Performance Evaluation in Taiwan**

In terms of SMS operational contributions, the first one is to develop the Taiwan airport SMS components and elements via ICAO and FAA airport SMS regulations reviewing, and the second one is to establish a SMS performance evaluation structure for Taiwan airport. The third one is to acquire the weights and ranking of airport SMS components and elements via ANP process. The fourth one is to develop performance evaluation of airport SMS via all elements operations assessments, and the final one is to discover the airport SMS performance rankings, the overall rankings in order are TPE, KHH and TSA.

In Part two research, the contributions in methodology are illustrated as follows: to establish an airport SMS network in order to obtain the weights of SMS components and elements and to develop two stage expert's surveys via ANP and fuzzy TOPSIS method, and finally to compare the airport SMS performance by both the weighted average and the fuzzy TOPSIS methods. Through the interviews, after second stage, with the airport SMS top managers, this study uncovers the current implementations of airport SMS for three airports which can be used to verify the results at the second stage and to point out the interrelation among C_2 (*Safety risk management*), C_3 (*Safety assurance*) and C_4 (*Safety promotion*) components.

5.3 Future Research

In research Part one, based on the process of safety data collection and analysis this study used the occurrence data to establish Poisson regression model to analyze the relationship between the occurrences and ICAO occurrences categories. Final judgments are going to be conducted by the authorities and administrators. Safety data is so important which helps understand how safety is incorporated in a target organization, thus, the data collection of airport safety events is equally important as the risk management component (C_2) of airport SMS. In order to support more quantitative information for the finding in Part two, future research will focus on safety events and analysis on root causes in airport surface and statistical analysis on the airport safety events data. This future research is intended to support the complete safety information to airport administrators, and to help the airport administrators to prevent safety events happening and to improve safety quality. Based on the complete statistical information on airport events, the SSP safety targets can be reached via critical airport SMS operations (see the shaded overlapping area in Fig. 1-1).

This study is also based on the unified ICAO and Taiwan CAA regulations to develop the airport SMS components and elements. But the scales of the international airports are different, which may cause different results. This merits future research in resources input based on airport scale and safety performance output. Safety data sharing is useful for aviation industries, government and academic experts to understand the safety events which can happen every day. The safety data standardization is helpful to exchange international safety information. As is well known, the *safety risk management* is the heart of airport SMS, so, the standardization made via ICAO regulation and European Co-ordination Centre for Accident and Incident Reporting Systems (ECCAIRS) is necessary and *Safety assurance* is the feedback of all system while safety information can be updated anytime. Furthermore, *Safety promotion* is not only for airport system, but also for the stakeholders of airport SMS including airline industries, passengers and staffs of airport, and then the *Safety policy and objectives* of airport can be followed and updated from the inner and outer stakeholders.

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Appendix 1: ICAO Sample Operation Grouping Categories

Occurrences category	Acronym	Description
Takeoff, Landing, and Ground Operation	***TLGO***	
Ground Handling	RAMP	Occurrences during (or as a result of) ground handling operations.
Ground Collision	GCOL	Collision while taxiing to or from a runway in use.
Loss of Control - Ground	LOC-G	Loss of aircraft control while the aircraft is on the ground.
Runway Excursion	RE	A veer off or overrun off the runway surface.
Runway Incursion - Vehicle, Aircraft or Person	RI-VAP	Any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle or person on the protected area of a surface designated for the landing and take-off of aircraft.
Runway Incursion- Animal	RI-A	Collision with, risk of collision, or evasive action taken by an aircraft to avoid an animal on a runway or on a helipad or helideck in use.
Undershoot or Overshoot	USOS	A touchdown off the runway or helipad or helideck surface.
Abnormal Runway Contact	ARC	Any landing or takeoff involving abnormal runway or landing surface contact.
Fire/Smoke (Post-Impact)	F-POST	Fire or Smoke resulting from impact.
Evacuation	EVAC	Occurrence where either; (a) person(s) are injured during an evacuation, (b) an unnecessary evacuation was performed, (c) evacuation equipment failed to perform as required, or (d) the evacuation contributed to the severity of the occurrence happened.
Airborne	***AIRBN***	
Airprox/TCAS Alert/Loss of Separation/Near Midair Collisions/ Midair Collisions	MAC	Airprox, ACAS alerts, loss of separation as well as near collisions or collisions between aircraft in flight.
Controlled Flight into/ toward Terrain	CFIT	In-flight collision or near collision with terrain, water, or obstacle without indication of loss of control.
Loss of Control- In flight	LOC-I	Loss of aircraft control while or deviation from intended flight path in-flight.
Fuel Related	FUEL	One or more power-plants experienced reduced or no power output due to fuel exhaustion, fuel

Occurrences category	Acronym	Description
		starvation/mismanagement, fuel contamination/wrong fuel, or carburetor and/or induction icing.
Low Attitude Operations	LALT	Collision or near collision with obstacles/objects/terrain while intentionally operating near the surface (excludes takeoff or landing phases).
Abrupt Maneuver	AMAN	The intentional abrupt maneuvering of the aircraft by the flight crew.
Weather	***WTHR***	
Windshear or Thunderstorm	WSTRW	Flight into windshear or thunderstorm.
Turbulence Encounter	TURB	In-flight turbulence encounter.
Icing	ICE	Accumulation of snow, ice, freezing rain, or frost on aircraft surfaces that adversely affects aircraft control or performance.
Aircraft	***ARCFT***	
System/Component Failure or Malfunction (Power plant)	SCF-PP	Failure or malfunction of an aircraft system or component - related to the power-plant.
System/Component Failure or Malfunction (Non-Power plant)	SCF-NP	Failure or malfunction of an aircraft system or component - other than the power-plant.
Fire/Smoke (Non-Impact)	F-NI	Fire or smoke in or on the aircraft, in flight or on the ground, which is not the result of impact.
Miscellaneous	***MISCN***	
Security Related	SEC	Criminal/Security acts which result in accidents or incidents (per the International Civil Aviation Organization [ICAO] Annex 13).
Cabin Safety Events	CABIN	Miscellaneous occurrences in the passenger cabin of transport category aircraft.
Other	OTHR	Any occurrence not covered under another category.
Unknown or Undetermined	UNK	Insufficient information exists to categorize the occurrence.
Non-aircraft-related	***NARCFT***	
ATM/CNS	ATM	Occurrences involving Air traffic management (ATM) or communications, navigation, or surveillance (CNS) service issues.
Aerodrome	ADRM	Occurrences involving aerodrome design, service, or functionality issues.

Appendix 2: Framework for ICAO Certified Aerodrome SMS

1. Safety policy and objectives (ICAO, 2011b)

1.1 Management commitment and responsibility

The certified aerodrome shall define the organization's safety policy which shall be in accordance with international and national requirements, and which shall be signed by the accountable executive of the organization. The safety policy shall reflect organizational commitments regarding safety; shall include a clear statement about the provision of the necessary resources for the implementation of the safety policy; and shall be communicated, with visible endorsement, throughout the organization. The safety policy shall include the safety reporting procedures; shall clearly indicate which types of operational behaviours are unacceptable; and shall include the conditions under which disciplinary action would not apply. The safety policy shall be periodically reviewed to ensure it remains relevant and appropriate to the organization.

1.2 Safety accountabilities

The certified aerodrome shall identify the accountable executive who, irrespective of other functions, shall have ultimate responsibility and accountability, on behalf of the certified aerodrome, for the implementation and maintenance of the SMS. The certified aerodrome shall also identify the accountabilities of all members of management, irrespective of other functions, as well as of employees, with respect to the safety performance of the SMS. Safety responsibilities, accountabilities and authorities shall be documented and communicated throughout the organization, and shall include a definition of the levels of management with authority to make decisions regarding safety risk tolerability.

1.3 Appointment of key safety personnel

The certified aerodrome shall identify a safety manager to be the responsible individual and focal point for the implementation and maintenance of an effective SMS.

1.4 Coordination of emergency response planning

The certified aerodrome shall ensure that an emergency response plan that provides for the orderly and efficient transition from normal to emergency operations and the return to normal operations is properly coordinated with the emergency response plans of those organizations it must interface with during the provision of its services.

1.5 SMS documentation

The certified aerodrome shall develop an SMS implementation plan, endorsed by senior management of the organization that defines the organization's approach to the management of safety in a manner that meets the organization's safety objectives. The organization shall develop and maintain SMS documentation describing the safety policy and objectives, the SMS requirements, the SMS processes and procedures, the accountabilities, responsibilities and authorities for processes and procedures, and the SMS outputs. Also as part of the SMS documentation, the certified aerodrome shall develop and maintain a Safety Management Systems manual (SMSM), to communicate its approach to the management of safety throughout the organization.

2. Safety risk management

2.1 Hazard identification

The certified aerodrome shall develop and maintain a formal process that ensures that hazards in operations are identified. Hazard identification shall be based on a combination of reactive, proactive and predictive methods of safety data collection.

2.2 Safety risk assessment and mitigation

The certified aerodrome shall develop and maintain a formal process that ensures analysis, assessment and control of the safety risks in aerodrome operations.

3. Safety assurance

3.1 Safety performance monitoring and measurement

The certified aerodrome shall develop and maintain the means to verify the safety performance of the organization and to validate the effectiveness of safety risk controls. The safety performance of the organization shall be verified in reference to the safety performance indicators and safety performance targets of the SMS.

3.2 The management of change

The certified aerodrome shall develop and maintain a formal process to identify changes within the organization which may affect established processes and services; to describe the arrangements to ensure safety performance before implementing changes; and to eliminate or modify safety risk controls that are no longer needed or effective due to changes in the operational environment.

3.3 Continuous improvement of the SMS

The certified aerodrome shall develop and maintain a formal process to identify the causes of substandard performance of the SMS, determine the implications of substandard performance of the SMS in operations, and eliminate or mitigate such causes.

4. Safety promotion

4.1 Training and education

The certified aerodrome shall develop and maintain a safety training programme that ensures that personnel are trained and competent to perform the SMS duties. The scope of the safety training shall be appropriate to each individual’s involvement in the SMS.

4.2 Safety communication

The certified aerodrome shall develop and maintain formal means for safety communication that ensures that all personnel are fully aware of the SMS, conveys safety-critical information, and explains why particular safety actions are taken and why safety procedures are introduced or changed.

Appendix 3: International Airport SMS Documentations

1. **The United Kingdom :** CAP128 Appendix 2C (UK CAA, 2011)

a) Safety policy and objectives

(1) Management commitment and responsibility

An effective safety policy, endorsed by the Accountable Manager, sets a clear direction for the aerodrome to follow and contributes to all aspects of business and safety performance. The safety policy should include a statement about the provision of adequate resources and show the commitment of senior management to manage safety effectively.

(2) Safety accountability

The aerodrome license holder should identify an Accountable Manager who is accountable for ensuring that all operational activities can be financed and carried out to the standard required.

(3) Appointment of key personnel

The aerodrome license holder should identify a manager to be the focal point for the implementation and day-to-day maintenance of an effective SMS.

(4) Coordination of emergency response planning

The aerodrome license holder should ensure that an emergency response plan provides for the orderly and efficient transition from normal to emergency operations and the return to normal operations. The plan should be properly coordinated with the emergency response plans of those organisations it must interface with during the provision of its services.

(5) SMS documentation

The aerodrome license holder should develop and maintain documentation describing the safety policy and objectives, the safety accountabilities and responsibilities of senior managers, the SMS processes and procedures and any outputs from the SMS. SMS documentation may be integrated in the existing Aerodrome Manual or a separate safety management system manual may be developed.

b) Safety Risk Management

(1) Hazard identification

The aerodrome license holder should develop and maintain an effective process to identify safety hazards affecting the operation. Hazard identification should be based on a combination of reactive (using safety data from an event that has happened), proactive (using safety data from a near miss report) and predictive (actively looking at normal day-to-day operations to see where potential problems *could occur) methods of safety data collection.*

(2) Safety risk assessment and mitigation

The aerodrome license holder should develop and maintain an effective process that ensures analysis and assessment of the safety risks in aerodrome operations, and should implement any remedial action necessary to maintain risks at a level as low as reasonably practicable. Risk assessments should be reviewed regularly, and when changes occur that may affect the safety hazards or the associated risks.

c) Safety Assurance

(1) Safety performance monitoring and measurement

The aerodrome license holder should ensure that safety performance is measured to determine whether safety measures are effective and to identify where improvement is needed. Self-monitoring such as incident investigation, safety inspections and safety audits is a part of this process.

(2) Management of change

The aerodrome license holder should assess the safety impact of any safety-significant changes upon other procedures and processes, individuals and the operation and organization as a whole. This should be done in the planning stages of any project, and updated as required.

(3) Continuous improvement of the SMS

The aerodrome license holder should identify and determine the implications of substandard performance of the SMS in operation, and eliminate or mitigate such causes.

d) Safety Promotion

(1) Training and education

The aerodrome license holder should ensure all aerodrome personnel and third-party contractors receive safety training as appropriate to their role to ensure they understand their safety responsibilities within the aerodrome's SMS.

(2) Safety communication

The aerodrome license holder should develop and maintain safety communication mechanisms which ensure safety critical information is conveyed effectively and explain why particular safety actions are taken and why safety procedures are introduced or changed.

2. **Australia:** (AC)-139-16(0) (CASA, 2005)

(1) Policy

(2) Management accountability

(3) Establishing a process to manage risks

(4) Setting up a reporting system to record hazards, risks and actions taken

(5) Training and educating staff

(6) Auditing the operation and investigating incidents and accidents

(7) Setting up a system to control documentation, data and

(8) Evaluating how the system is operating.

The above eight step processes are compliant with ICAO airport SMS framework (ICAO, 2011b). The first and second steps belong to ICAO airport SMS component for Safety policy and objectives, and the third, fourth and seventh steps belong to the component for Safety risk management. The fifth step belongs to the SMS component for Safety promotion, and the sixth and eighth steps belong to the SMS component for Safety assurance.

3. **The United States**: AC 150/5200-37 (FAA, 2007)

(1) Safety Policy and Objectives

- *Safety Policy*
  - *The commitment of senior management to implement SMS*
  - *A commitment to continual safety improvement*
  - *The encouragement of employees to report safety issues without fear of reprisal*
  - *A commitment to provide the necessary safety resources*
  - *A commitment to make safety the highest priority*
- *Safety objectives*
  - *The organization's policy concerning responsibility and accountability*
  - *Identification within the system of someone responsible for administration of the overall SMS*
  - *At larger airports, operations may support the Safety Manager being a full-time permanent employee and in some cases having a support staff*
  - *The responsibilities of the Safety Manager are clearly defined along with identified lines of communication within the organization*
  - *Depending on the size and complexity of the airport's operation, it may be useful to establish a safety committee*

(2) Safety Risk Management

- *Determines associated risk(s)*
- *Identifies the severity and probability of the occurring risk(s)*
- *Develop mitigation strategies as appropriate*

- *Applies, tracks, and monitors the mitigation strategy*
- *Assess and modifies strategies as necessary*

(3) Safety Assurance

- *Develop identified safety performance indicators and targets*
- *Monitor adherence to safety policy through self-auditing*
- *Allocate adequate resources for safety oversight*
- *Solicit input through a non-punitive safety reporting system*
- *Systematically review all available feedback from daily self-inspections, assessments, reports, safety risk analysis, and safety audits*
- *Communicate findings to staff and implement agreed-upon mitigation strategies*
- *Promote integration of a systems approach to safety into the overall operation of the airport*

(4) Safety Promotion:

Safety promotion should include:

- *Training and education*
- *Safety communication*
- *Safety competency and continuous improvement*

Safety training and education should consist of the following:

- *A documented process to identify training requirements*
- *A validation process that measures the effectiveness of training*
- *Initial (general safety) job-specific training*
- *Recurrent safety training*
- *Indoctrination/initial training incorporating SMS*
- *Training that includes human factors and organizational factors*

4. Canada: AC300-002 (TCCA, 2009)

a) Proactive processes.

b) Documented policies and procedures that are relevant to a).

c) Training for personnel assigned to duties under the SMS that are relevant to a).

During phase 4, the certified holder shall demonstrate the components of Training, Quality assurance and Emergency preparedness to achieve airport SMS.

The airport SMS for AC 300-002 by TCCA is described as follows:

1. *Safety management plan*
   - *Safety policy*
   - *Non-punitive reporting policy*
   - *Roles, responsibilities and employee involvement*
   - *Communication*
   - *Safety planning, objectives and goals*

- *Performance measurement*
- *Management review*

2. *Document management*
    - *Identification and maintenance of applicable regulations*
    - *SMS documentation*
    - *Records management*
3. *Safety oversight*
    - *Reactive processes*
    - *Proactive processes*
    - *Investigation and analysis*
    - *Risk management*
4. *Training*
    - *Training, awareness and competence*
5. *Quality assurance*
    - *Quality assurance*
6. *Emergency preparedness*
    - *Emergency preparedness and response*

Appendix 4: The first stage experts' questionnaires

第一階段專家問卷

臺灣機場 SMS 作業之權重值評估

問卷編號：______

您好：

本問卷為國立成功大學交通管理科學研究所接受國科會委託進行「臺灣機場 SMS 作業之績效評估研究」，本研究共分二階段，此為**第一階段專家問卷**，希望藉由您專業的素養及寶貴的意見，**評估臺灣機場 SMS 作業要項與要素之權重值。**

問卷所有資料僅作為學術研究參考之用，絕不對外公開。本研究需要您的專業知識與意見指教，敬請於 **2012 年 9 月 14 日**前填寫完畢並寄回問卷，再次感謝您撥冗惠賜指教。

敬祝　平安喜樂

國立成功大學　交通管理科學研究所
指導教授　張有恆　教授兼管理學院院長
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指導教授　陳占平　教授

博士研究生　邵珮琪　敬上

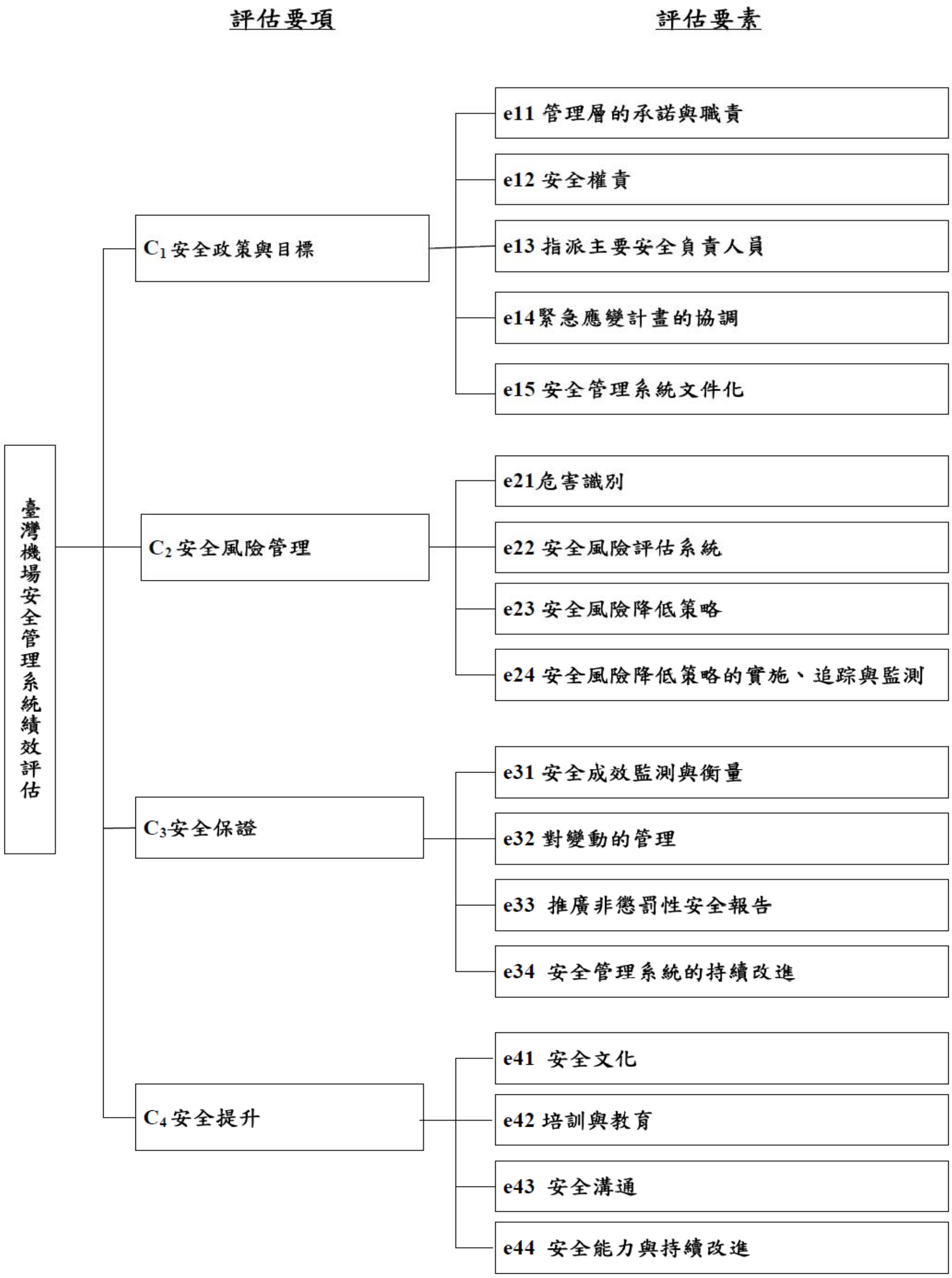
【問卷填寫說明】

1. **本研究之目的為「機場 SMS 作業之績效評估」， 主要擷取機場 SMS 作業的要項與要素權重值，並決定機場 SMS 作業要素之優先順序。**
2. 請您針對機場 SMS 作業的要項與要素之間的相對重要性進行評估。
3. 本次問卷中之機場 SMS 作業之構成要項與要素乃經 ICAO Safety Management Manual (SMM)、CAA 民用機場設計暨運作規範-附錄 7 與美國 FAA Advisory Circular AC150/5200-37 之相關法規彙整說明，詳細定義請參考表一。
4. 第一階段專家問卷完成後，本研究將致酬金 500 元，以示謝忱。

(下頁接續)

【附件】

根據 ICAO、CAA 與 FAA 之相關機場 SMS 法規，本研究將臺灣機場 SMS 作業績效評估架構歸納如圖一所示。



圖一　臺灣機場 SMS 作業績效評估層級架構圖

表一　機場 SMS 作業評估要項與要素說明

評估要項	評估要素	說明
C_1 安全政策與目標	e_{11} 管理層的承諾與職責	1. 機場須制定其組織的安全政策，以符合國際與國內要求，並由機場權責主管簽名發布。 2. 安全政策應反應機場的安全承諾，並為安全政策提供必要資源。 3. 安全政策應含安全通報程序。 4. 安全政策應定期檢視，確保對機場的適用性
	e_{12} 安全權責	1. 機場應確認權責主管人員，對實施並維持 SMS 作業負有最終的權責與職責。 2. 安全權責、權責與職責須文件化並傳達機場組織周知。
	e_{13} 指派主要安全負責人員	指派一安全經理，擔任機場 SMS 的負責人與協調人，並維持 SMS 有效運作。
	e_{14} 緊急應變計畫的協調	1. 機場應確保緊急應變計畫能有效的令機場作業由正常運作過渡至緊急運作，最後恢復至正常運作。 2. 確保與機場相關之機構的緊急應變計畫已進行良好協調。
	e_{15} 安全管理系統文件化	1. 機場須制定並保存 SMS 文件，用以敍述： (1) 機場安全政策、安全目標 (2) SMS 的要求、措施及程序 (3) SMS 的措施及程序所需的權責、職責和權力 (4) 機場 SMS 的成果 2. 機場須制定與公告安全管理手冊(SMSM)
C_2 安全風險管理	e_{21} 危害識別	1. 機場危害識別程序須綜合被動性(reactive)、主動性(proactive)與預測性(predictive)，利於安全資料的收集與分析。 2. 危害識別應考慮機場系統中所有可能失效源頭，根據失效性質可分為： (1) 設備 (The equipment) (2) 作業環境(Operating environment) (3) 人為因素(Human element) (4) 作業程序(Operation procedure) (5) 維修程序(Maintenance procedure) (6) 外部服務(External service)

表一　機場 SMS 作業評估要項與要素說明 (續)

評估要項	評估要素	說明
C_2 安全風險管理	e_{22} 安全風險評估系統 (註 1)	機場應建立風險預測矩陣(Predictive Risk Matrix)，針對事故或事件的風險的可能性(likelihood)與嚴重性(severity)加以評估，以進行事故與事件的預測與預防。
	e_{23} 安全風險降低策略 (註 1)	將風險水準(risk level)運用於風險矩陣中，利用風險的嚴重度可分為下列三級: 1. 高度風險(High risk)- 不可接受之風險水準：該作業或建議活動均不能實施，直到風險水準控制在中度或低度水準。 2. 中度風險(Medium risk)- 可接受的風險水平：最小可接受的安全目標，屬可接受建議改進的範圍令作業與活動可以繼續。 3. 低度風險(Low risk)- 風險水準目標：沒有限制或限制可接受的作業活動。
	e_{24} 安全風險降低策略的實施、追蹤與監測 (註 2)	根據風險水準，其應對策簡述如下： 1. 高度風險(High risk)- 危害如減輕後，持續追蹤監測與管理，但實施任何建議與控制實施，皆需管理人員批准。 2. 中度風險(Medium risk)- 危害改進後將持續追蹤監測與管理。 3. 低度風險(Low risk)- 不須積極管理，但仍應記錄。
C_3 安全保證	e_{31} 安全成效監測與衡量	透過自我督查(self-auditing)、外部督查(external auditing)以及安全監督(safety oversight)來實現機場作業活動的安全監測與衡量。
	e_{32} 對變動的管理	機場應有一完整程序，以查明因變動而對機場內作業程序與服務產生影響，此程序應於變動前完成，並確保安全成效的安排，並取消因變動而不需存在的安全風險控制措施。
	e_{33} 推廣非懲罰性安全報告 (註 2)	機場 SMS 應包括：由管理階層支持的非懲罰性的安全報告制度，該制度應請與危害及安全有關的人員負責其回饋作業。
	e_{34} 安全管理系統的持續改進	機場需制定一程序，以查明機場 SMS 低於標準成效的原因與影響，利用各式督查，以回饋(feedback)與循環(cycle) 機制來評估 SMS 的成效。

表一　機場 SMS 作業評估要項與要素說明 (續)

評估要項	評估要素	說明
C_4 安全提升	e_{41} 安全文化 (註 2)	1. 安全文化: 為機場組織與個人對安全所表現出的態度與組織結構。 2. 有效的安全文化包含: 明確的報告方式、明確的界定職責以及對程序充分理解。 3. 機場人員應充分了解自己的職責、知道何時該安全報告、報告內容為何以及由何人提出安全報告。 4. 機場高階管理人員不僅審查機場組織的財務表現，也包括安全績效表現。
	e_{42} 培訓與教育	機場須具備一套安全培訓計畫，以確保人員能勝任並履行機場 SMS 作業的責任。
	e_{43} 安全溝通	1. 機場應有正式管道與程序，傳達重要安全資訊、解釋採取安全行動及更改安全作業程序的原因。 2. 機場安全溝通方式包括： (1) 安全研討會(Safety seminars) (2) 安全信件、通知與公告(Safety letter, notices and bulletins) (3) 安全經驗學習(Safety lesson-learning) (4) 佈告欄(Bulletin board)、安全報告投擲信箱(Safety report drop boxes)以及利用網站或電子郵件傳送電子報告。
	e_{44} 安全能力與持續改進	為了確保機場工作人員的安全能力，與持續改進專業能力，機場安全培訓與教育內容應包括： (1) 培訓文件流程，以確定培訓需求 (2) 安全驗證流程，以衡量訓練成效 (3) 週期性的安全複訓 (4) 人為因素與組織因素的培訓

註 1: **e_{22} 安全風險評估系統、e_{23} 安全風險降低策略** 二要素來自於民航局 100 年發佈的「民用機場設計暨運作規範」附錄七-安全管理系統之要素: 安全風險評估與降低策略，本研究參考 FAA　AC150/5200-37 後，依作業內容分為 e_{22} 與 e_{23} 兩要素，敬請參閱表一說明。

註 2: **e_{24} 安全風險降低策略的實施、追蹤與監測 、e_{33} 推廣非懲罰性安全報告與 e_{41} 安全文化** 三項要素為本研究參考 FAA 的 AC150/5200-37 之機場 SMS 之**安全風險管理、安全保證與安全提升**三要項各增加的三個要素。

(下頁接續)

評估機場 SMS 作業要項之間的相關性

【問卷填寫說明】

1. 為了解要項間的相關性，問卷的第一部分調查各要項的**個別重要程度**，以建構機場 SMS 業要項之間的關係。
2. 各要項之重要性評分以 1 至 10 分來表達，**數值越高代表該要項重要程度越高，數值越低則表示該要項越不重要**。

【範例】

下表即為評估A、B要項之**個別重要性程度**，分別給予6分與8分的重要性評估。

重要性分數	1	2	3	4	5	6	7	8	9	10
要項A						**X**				
要項B								**X**		

評估機場 SMS 作業之要項與要素的權重值

【問卷填寫說明】

1. 本問卷利用 1 到 9 的等級，進行「評估要項」與「評估要素」間相對重要性強度之比較。每一準則對總體目標的影響程度不盡相同，各準則對目標之達成有相對權重，也因此能顯示出各要項或要素之間的權重比較，就各要項或要素評比勾選出最適當比值。
2. 若您認為評估要項中要項 A 比要項 B 重要，請您在表中相對應欄位打勾，以此類推。
3. 各要項比較時，必須符合遞移律，若要項 A 比要項 B 重要(A>B)，且要項 B 比要項 C 重要(B>C)，則要項 A 也比要項 C 重要(A>C)，意即，A>B>C 必須成立。

【範例】

(1) 若您在評選各準則時，認為「評估要項 A」之重要性「頗強」於「評估要項 B」，則請於「**頗強**」欄中勾選(即於**頗強欄**內之 5:1 或 4:1 處畫 **X**)；若您認為「評估要項 A」之重要性「稍強」於「評估要項 C」，則請於「**稍強**」欄中勾選(即於**稍強欄**內之 2:1 或 3:1 處畫 **X**)，如下表所示。

(2) 若您在評選各準則時，認為「評估要項 B」之重要性「稍弱」於「評估要項 C」，則請於「稍弱」欄中勾選(即於**稍弱欄**內之 1:2 或 1:3 處畫 **X**) ，如下表所示。

要項	重要性程度 A:B																	要項
	絕強		極強		**頗強**		**稍強**		同	**稍弱**		頗弱		極弱		絕弱		
尺度	**9:1**	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	尺度
評估要項 A						**X**												評估要項 B
								X										評估要項 C
評估要項 B										**X**								評估要項 C

【問卷內容第一部分：機場 SMS 作業要項之相關性評估】

在您參照過表一的說明後，請針對機場 SMS 作業之要項：「安全政策與目標」、「安全風險管理」、「安全保證」及「安全提升」四個要項，進行**個別重要程度**評分，**數值越高代表該要項重要程度越高**，**數值越低則表示該要項越不重要**。。

重要性分數 / 要項別	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
安全政策與目標(C1)										
安全風險管理(C2)										
安全保證(C3)										
安全提升(C4)										

（下頁接續）

【問卷內容─機場 SMS 作業要項之相對重要性比較】

針對機場 SMS 作業之要項而言，請就「安全政策與目標」、「安全風險管理」、「安全保證」及「安全提升」四個作業要項評估其相對重要程度。

要項 A	重要性程度 A:B																	要項 B
	絕強		極強		頗強		稍強		同	稍弱		頗弱		極弱		絕弱		
尺度	**9:1**	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	尺度
安全政策與目標(C1)																		安全風險管理(C2)
																		安全保證(C3)
																		安全提升(C4)
安全風險管理(C2)																		安全保證(C3)
																		安全提升(C4)
安全保證(C3)																		安全提升(C4)

（下頁接續）

【問卷內容─機場 SMS 作業要素之相對重要性比較】

1.針對機場 SMS 作業「安全政策與目標」要項而言，請您對所擬選的要素之間相對重要性做評比。

要素 A	重要性程度 A:B																	要素 B
	絕強		極強		頗強		稍強		同	稍弱		頗弱		極弱		絕弱		
尺度	**9:1**	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	尺度
管理層的承諾與職責(e_{11})																		安全權責(e_{12})
																		指派主要安全負責人員(e_{13})
																		緊急應變計畫的協調(e_{14})
																		安全管理系統文件化(e_{15})
安全權責(e_{12})																		指派主要安全負責人員(e_{13})
																		緊急應變計畫的協調(e_{14})
																		安全管理系統文件化(e_{15})
指派主要安全負責人員(e_{13})																		緊急應變計畫的協調(e_{14})
																		安全管理系統文件化(e_{15})
緊急應變計畫的協調(e_{14})																		安全管理系統文件化(e_{15})

2.針對機場 SMS 作業「**安全風險管理**」要項而言，請您對所擬選的要素之間相對重要性做評比。

要素 A	重要性程度 A:B																	要素 B
	絕強		極強		頗強		稍強		同	稍弱		頗弱		極弱		絕弱		
尺度	**9:1**	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	尺度
危害識別(e_{21})																		安全風險評估系統(e_{22})
																		安全風險降低策略(e_{23})
																		安全風險降低策略的實施、追蹤與監測(e_{24})
安全風險評估系統(e_{22})																		安全風險降低策略(e_{23})
																		安全風險降低策略的實施、追蹤與監測(e_{24})
安全風險降低策略(e_{23})																		安全風險降低策略的實施、追蹤與監測(e_{24})

3. 針對機場 SMS 作業「**安全保證**」要項而言，請您對所擬選的要素之間相對重要性做評比。

要素 A	重要性程度 A:B																	要素 B
	絕強		極強		頗強		稍強		同	稍弱		頗弱		極弱		絕弱		
尺度	**9:1**	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	尺度
安全成效監測與衡量(e_{31})																		對變動的管理(e_{32})
																		推廣非懲罰性安全報告 (e_{33})
																		安全管理系統的持續改進 (e_{34})
對變動的管理(e_{32})																		推廣非懲罰性安全報告 (e_{33})
																		安全管理系統的持續改進 (e_{34})
推廣非懲罰性安全報告 (e_{33})																		安全管理系統的持續改進 (e_{34})

4. 針對機場 SMS 作業之「**安全提升**」要項而言，請您對所擬選的要素之間相對重要性做評比。

要素 A	重要性程度 A:B																	要素 B
	絕強		極強		頗強		稍強		同	稍弱		頗弱		極弱		絕弱		
尺度	**9:1**	**8:1**	**7:1**	**6:1**	**5:1**	**4:1**	**3:1**	**2:1**	**1:1**	**1:2**	**1:3**	**1:4**	**1:5**	**1:6**	**1:7**	**1:8**	**1:9**	尺度
安全文化(e_{41})																		培訓與教育(e_{42})
																		安全溝通(e_{43})
																		安全能力與 持續改進 (e_{44})
培訓與教育(e_{42})																		安全溝通(e_{43})
																		安全能力與 持續改進 (e_{44})
安全溝通(e_{43})																		安全能力與 持續改進 (e_{44})

姓名：________________________服務單位：________________________

職稱：________________________年資：____________________(請務必填具)

聯絡電話：___________________________________

電子信箱：___________________________________

請留下您的寶貴意見

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本問卷到此結束，再次感謝您協助指導本研究！

Appendix 5: The second stage experts' questionnaires

第二階段專家問卷

臺灣機場 SMS 作業之績效評估

問卷編號：___

您好：

本問卷為國立成功大學交通管理科學研究所接受國科會委託進行「臺灣機場 SMS 作業之績效評估研究」，本研究共分二階段，此為**第二階段專家問卷**，敬請閱讀本問卷說明及臺灣桃園、高雄與松山國際機場安全管理系統手冊後，
藉由您對機場 SMS 作業的認知與專業素養，進行**臺灣桃園、高雄與松山國際機場 SMS 作業績效之評估。**

問卷所有資料僅作為學術研究參考之用，絕不對外公開。本研究需要您的專業知識與意見指教，敬請於 **2012 年 9 月 30 日前填寫完畢並寄回問卷**，再次感謝您撥冗惠賜指教。

敬祝　平安喜樂

國立成功大學　交通管理科學研究所
指導教授　張有恆　教授兼管理學院院長
國立成功大學　會計系/財務金融研究所
指導教授　陳占平　教授

博士研究生　邵珮琪　敬上

【問卷填寫說明】

1. 本研究之目的為「**臺灣機場 SMS 作業之績效評估**」，以**五種模糊語意尺度進行各要項與要素間之績效評估**。
2. 本次專家問卷，其目的在於評估**臺灣桃園、高雄與松山國際機場 SMS 作業的績效**，並建立機場 SMS 作業評估模式。
3. 本次問卷中之機場 SMS 作業之構成要項與要素乃經 ICAO Safety Management Manual (SMM)、CAA 民用機場設計暨運作規範-附錄 7 與美國 FAA Advisory Circular AC150/5200-37 之相關法規彙整說明，詳細定義請參考表一。
4. 第二階段專家問卷完成後，本研究將致酬金 500 元，以示謝忱。

(下頁接續)

表一　機場 SMS 作業評估要項與要素說明

評估要項	評估要素	說明
C_1 安全政策與目標	e_{11} 管理層的承諾與職責	1. 機場須制定其組織的安全政策，以符合國際與國內要求，並由機場權責主管簽名發布。 2. 安全政策應反應機場的安全承諾，並為安全政策提供必要資源。 3. 安全政策應含安全通報程序。 4. 安全政策應定期檢視，確保對機場的適用性
	e_{12} 安全權責	1. 機場應確認權責主管人員，對實施並維持 SMS 作業負有最終的權責與職責。 2. 安全權責、權責與職責須文件化並傳達機場組織周知。
	e_{13} 指派主要安全負責人員	指派一安全經理，擔任機場 SMS 的負責人與協調人，並維持 SMS 有效運作。
	e_{14} 緊急應變計畫的協調	1. 機場應確保緊急應變計畫能有效的令機場作業由正常運作過渡至緊急運作，最後恢復至正常運作。 2. 確保與機場相關之機構的緊急應變計畫已進行良好協調。
	e_{15} 安全管理系統文件化	1. 機場須制定並保存 SMS 文件，用以敘述： (1) 機場安全政策、安全目標 (2) SMS 的要求、措施及程序 (3) SMS 的措施及程序所需的權責、職責和權力 (4) 機場 SMS 的成果 2. 機場須制定與公告安全管理手冊(SMSM)
C_2 安全風險管理	e_{21} 危害識別	1. 機場危害識別程序須綜合被動性(reactive)、主動性(proactive)與預測性(predictive)，利於安全資料的收集與分析。 2. 危害識別應考慮機場系統中所有可能失效源頭，根據失效性質可分為： (1) 設備 (The equipment) (2) 作業環境(Operating environment) (3) 人為因素(Human element) (4) 作業程序(Operation procedure) (5) 維修程序(Maintenance procedure) (6) 外部服務(External service)

表一　機場 SMS 作業評估要項與要素說明 (續)

評估要項	評估要素	說明
C_2 安全風險管理	e_{22} 安全風險評估系統 (註 1)	機場應建立風險預測矩陣(Predictive Risk Matrix)，針對事故或事件的風險的可能性(likelihood)與嚴重性(severity)加以評估，以進行事故與事件的預測與預防。
	e_{23} 安全風險降低策略 (註 1)	將風險水準(risk level)運用於風險矩陣中，利用風險的嚴重度可分為下列三級: 1. 高度風險(High risk)- 不可接受之風險水準：該作業或建議活動均不能實施，直到風險水準控制在中度或低度水準。 2. 中度風險(Medium risk)- 可接受的風險水平：最小可接受的安全目標，屬可接受建議改進的範圍令作業與活動可以繼續。 3. 低度風險(Low risk)- 風險水準目標：沒有限制或限制可接受的作業活動。
	e_{24} 安全風險降低策略的實施、追蹤與監測 (註 2)	根據風險水準，其應對策簡述如下： 1. 高度風險(High risk)- 危害如減輕後，持續追蹤監測與管理，但實施任何建議與控制實施，皆需管理人員批准。 2. 中度風險(Medium risk)- 危害改進後將持續追蹤監測與管理。 3. 低度風險(Low risk)- 不須積極管理，但仍應記錄。
C_3 安全保證	e_{31} 安全成效監測與衡量	透過自我督查(self-auditing)、外部督查(external auditing)以及安全監督(safety oversight)來實現機場作業活動的安全監測與衡量。
	e_{32} 對變動的管理	機場應有一完整程序，以查明因變動而對機場內作業程序與服務產生影響，此程序應於變動前完成，並確保安全成效的安排，並取消因變動而不需存在的安全風險控制措施。
	e_{33} 推廣非懲罰性安全報告 (註 2)	機場 SMS 應包括：由管理階層支持的非懲罰性的安全報告制度，該制度應請與危害及安全有關的人員負責其回饋作業。
	e_{34} 安全管理系統的持續改進	機場需制定一程序，以查明機場 SMS 低於標準成效的原因與影響，利用各式督查，以回饋(feedback)與循環(cycle) 機制來評估 SMS 的成效。

表一　機場 SMS 作業評估要項與要素說明 (續)

評估要項	評估要素	說明
C_4 安全提升	e_{41} 安全文化 (註 2)	1. 安全文化: 為機場組織與個人對安全所表現出的態度與組織結構。 2. 有效的安全文化包含: 明確的報告方式、明確的界定職責以及對程序充分理解。 3. 機場人員應充分了解自己的職責、知道何時該安全報告、報告內容為何以及由何人提出安全報告。 4. 機場高階管理人員不僅審查機場組織的財務表現，也包括安全績效表現。
	e_{42} 培訓與教育	機場須具備一套安全培訓計畫，以確保人員能勝任並履行機場 SMS 作業的責任。
	e_{43} 安全溝通	1. 機場應有正式管道與程序，傳達重要安全資訊、解釋採取安全行動及更改安全作業程序的原因。 2. 機場安全溝通方式包括： (1) 安全研討會(Safety seminars) (2) 安全信件、通知與公告(Safety letter, notices and bulletins) (3) 安全經驗學習(Safety lesson-learning) (4) 佈告欄(Bulletin board)、安全報告投擲信箱(Safety report drop boxes)以及利用網站或電子郵件傳送電子報告。
	e_{44} 安全能力與持續改進	為了確保機場工作人員的安全能力，與持續改進專業能力，機場安全培訓與教育內容應包括： (1) 培訓文件流程，以確定培訓需求 (2) 安全驗證流程，以衡量訓練成效 (3) 週期性的安全複訓 (4) 人為因素與組織因素的培訓

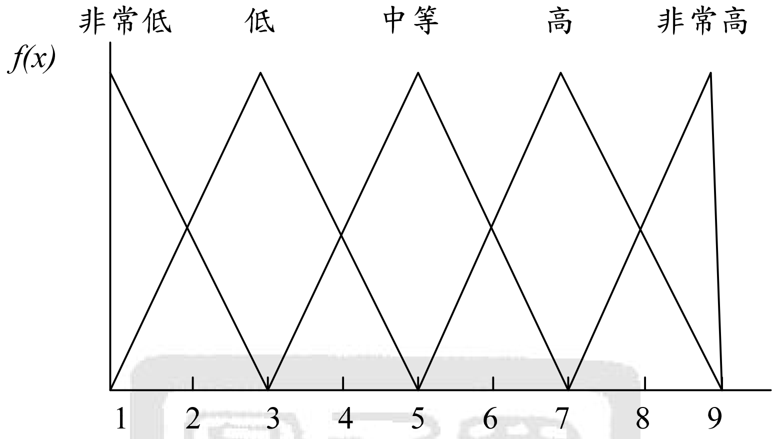
註 1: **e_{22} 安全風險評估系統、e_{23} 安全風險降低策略** 二要素來自於民航局 100 年發布的「民用機場設計暨運作規範」附錄七-安全管理系統之要素: 安全風險評估與降低策略，本研究參考 FAA　AC150/5200-37 後，依作業內容分為 e_{22} 與 e_{23} 兩要素，敬請參閱表一說明。

註 2: **e_{24} 安全風險降低策略的實施、追蹤與監測 、e_{33} 推廣非懲罰性安全報告與 e_{41} 安全文化** 三項要素為本研究參考 FAA 的 AC150/5200-37 之機場 SMS 之**安全風險管理、安全保證與安全提升**三要項各增加的三個要素。

(下頁接續)

【問卷設計說明】

本研究採用模糊語意衡量**臺灣機場 SMS 作業要素之績效**，問卷評估尺度區分為「非常低」、「低」、「中等」、「高」以及「非常高」五種語意尺度(參見圖一)，當您填寫問項時，請圈選機場 SMS 作業要素之績效語意評估，謝謝您的合作。



圖一 問項之五等級模糊語意衡量尺度

【問卷填寫範例】

在範例作業要項下，進行作業績效評估，從五等級語意尺度之中各圈選其績效表現，如下表所示：

範例作業要項	**績效評估尺度**				
	非常低	**低**	**中等**	**高**	**非常高**
XXX 作業	□	■	□	□	□
YYY 作業	□	□	□	■	□

(下頁接續)

【問卷內容：臺灣機場 SMS 作業要素之績效評估】

敬請參閱**表一說明**與**臺灣桃園、高雄與松山國際機場安全管理系統手冊(及其手冊附錄之 SMS 差異分析表)**後，再進行各要素之績效評估，請注意：<u>本問卷為**單選評估**，請以**打勾**表示</u>。

1. 針對「$\mathbf{C_1}$ 安全政策與目標」要項下的 5 個要素進行績效評估：

要素項目	評估機場	要素績效評估尺度				
		非常低	低	中等	高	非常高
e_{11} 管理層的承諾與職責	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{12} 安全權責	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{13} 指派主要安全負責人員	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{14} 緊急應變計畫的協調	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{15} 安全管理系統文件化	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐

(下頁接續)

2. 針對「C_2 安全風險管理」要項下的 4 個要素進行績效評估：

要素項目	評估機場	要素績效評估尺度				
		非常低	低	中等	高	非常高
e_{21} 危害識別	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{22} 安全風險評估系統	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{23} 安全風險降低策略	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{24} 安全風險降低策略的實施、追蹤與監測	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐

3. 針對「C_3 安全保證」要項下的 4 個要素進行績效評估：

要素項目	評估機場	要素績效評估尺度				
		非常低	低	中等	高	非常高
e_{31} 安全成效監測與衡量	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{32} 對變動的管理	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{33} 推廣非懲罰性安全報告	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{34} 安全管理系統的持續改進	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐

(下頁接續)

4. 針對「C_4安全提升」要項下的 4 個要素進行績效評估：

要素項目	評估機場	要素績效評估尺度				
		非常低	低	中等	高	非常高
e_{41} 安全文化	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{42} 培訓與教育	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{43} 安全溝通	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐
e_{44} 安全能力與持續改進	桃園機場	☐	☐	☐	☐	☐
	高雄機場	☐	☐	☐	☐	☐
	松山機場	☐	☐	☐	☐	☐

【專家資料填寫】

姓名：______________________ 服務單位：______________________

職稱：_____________________ **年資：**___________________(請務必填具)

聯絡電話：__________________ 電子信箱：______________________________

請留下您的寶貴意見

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問卷內容到此結束，感謝您協助指導本研究！

Appendix 6: The questions and answers for A, B, and C international airport SMS operations

評估要項	訪談問項與回答
機場安全管理系統整體評估	一、 SMS 作業是否與機場使用者群連結(如: 航空公司與勤務公司)與合作? 1. A 機場現行作業: (1) 安全管理委員會- 半年一會(成員請參照 TPE 安全委員會手冊附錄 A, 成員皆為與機場作業直接相關之利害關係單位) (2) 安全工作分組會議- 每季一會，分為: 航務、維護、輸油、飛航服務與貨運分組。 (3) 營運控制中心 (Operation Control Center, OCC)-與機場各單位資訊整合，其中包括承包商的施工進度掌握及動態業務管理。 2. B 機場現行作業: (1) 安全委員會：由航站主任主持，每半年一次。(委員組成為機場利害關係人: 包括航務組、近場塔台與區台、航空公司、油品公司、空廚公司、租賃公司、貨運快遞公司、勤務公司) (2) 安全工作小組會議，由航務組長主持，每半年一次，就機場相關安全議題進行狀況評估與改善，並將改善結果陳報於安全委員會。 (3) 機坪安全會議: 航務組組長主持，每月一次參與者為航空公司代表及地勤代理公司代表。 (4) 飛航駕駛員會議:航務組長主持，每季輪流邀請各航空公司飛航駕駛員與高雄機場塔臺、近場臺、裝修區臺、氣象臺等單位進行座談與建議。 (5) 跑道安全小組會議：航務組長主持，每季就跑道滑行道安全議題進行檢討與建議。

評估要項	訪談問項與回答
	3. C 機場現行作業: (1) 空側管理協調會:每月由航務組和航站作業利害關係單位，如:航空公司、油料公司及地勤代理公司等。(主要針對馬上可處理的問題加以討論，而非風險評估會議) (2) 分組月會:依航務、站務、場站與飛航服務作業進行每月一次的例行安全管理會議。 (3) 航機動線會議: 為臨時性質會議，由航務組主導，針對航務巡場缺失與業務別進行檢討與追蹤。
C_1 安全政策與目標	二、 對 A 機場而言，**C_1 安全政策與目標**之作業表現優於他站，探討 **e_{13} 指派主要安全負責人員**作業現況。 1. A 機場現行作業: (1) 航務員或航務工程師的任用，需要經專職科目之測驗與面試。 (2) 航務相關之新進人員，皆需接受民航局航訓所之安全管理系統(SMS)課程。 三、對 C 機場而言，**e_{11} (管理層的承諾與職責)** 表現遜於他站，探討原因或施行困難處。 1. 航站最高主管皆支持航務中階主管，航務組之機坪管理標準為從嚴，中階主管對一線作業人員視事件嚴重程度進行先勸導，再以點數記錄。 2. 屬軍民合用機場，部分停機坪是由軍方所管理，軍方場面管理規範與民航機場有所差異，故於進行相關措施時，無法全面施行，如軍方航機滑行使用之 ABD 缺口因屬軍方專用，無公布於飛航指南中。 四、B 機場 **e_{12} (安全權責)** 表現遜於其他二站，探討原因或施行困難處。 B 機場之站主管進行安全承諾，並以授權的方式，責陳航務組組長進行機場 SMS 作業監理，而航站主管與航務組組長為民航局指派。

評估要項	訪談問項與回答
C_2 安全風險管理	**五、對 C 機場而言，C_2 安全風險管理作業表現優於他站，探討 e_{21} 危害識別作業現況或其他供他站參考之處。** C 機場現行做法: 1. 航務組與機場作業人員之信賴感與群體安全共識高。如停機線人員向航務組提報安全風險事件，互動良好。 2. 於空側管理協調會中，充分反應利害關係單位或個人(如航空公司、駕駛員、勤務人員)的意見，以最快的速度處理風險事件或列入管理。 **六、對 A 機場而言，e_{21} 危害識別作業評估結果遜於他站，探討其施行現況或困難處。** A 機場以跑道整修作業說明: 應因跑道整修所存在的潛在風險，A 機場的對策與行動如下: TPE 跑道整建期間(102.06~103.02)，機場公司為了降低跑道危害風險(如 FOD)，現行措施如下： 1. 聯合巡場: 於航班離峰期由塔台管制單位與航務處聯合進行跑道及場面的巡場作業(半小時/次)。 2. 加強 FOD 的巡查：以 S 型的巡場路徑進行場面檢測 FOD。 3. 引進 iFerret™先進影像偵測系統 (Stratech's *intelligent* Vision FOD Detection System)，與跑道整修時一起裝設。 4. 為了防止鳥擊事件，2003 年引入驅鳥雷達系統- MERLIN Bird Strike Avoidance Radar System。這套系統現役於美國達拉斯國際機場與路易斯威爾國際機場 (Dallas Fort-Worth International Airport & Louisville International Airport) 5. 場內駕照的考核，未來將引進路考模擬系統，以利情境設置來測驗考照者。 **七、對 B 機場而言，e_{24} 安全風險降低策略的實施、追蹤與監測作業表現遜於他站，探討其施行現況。** B 機場目前安全風險的監測單位為高雄航站航務組。目前實施的現況是以在地文化，將安全風險觀念和緩融入工作中。 1. 依安全事件的嚴重性進行後續的評估作業，如情節並非重大，先以口頭告誡及勸導為主 。 2. 高雄機場網站之 SMS 專區標準作業表格：機場員工、航空公司人員及地勤代理作業人員。 3. 航務組安全危害通報表: 聯絡與業管單位為航務組。

<table>
<tr><th>評估要項</th><th>訪談問項與回答</th></tr>
<tr><td>C₃安全保證</td><td>
八、探討 B 機場的 e33 (推廣非懲罰性安全報告)現行做法，特別之處為何?
B 機場現行做法:
1. 依安全事件的嚴重性進行後續的評估作業，如情節並非重大，先以口頭告誡及勸導為主 。(平日作業則互相提醒、主動互相監督作業)
2. 航務組安全危害通報表: 聯絡與業管單位為航務組。

九、對 A 機場而言，e32 對變動的管理項目與 e33 推廣非懲罰性安全報告項目表現評估結果遜於他站，請分項說明 A 機場施行現況或作業困難之處。
1. e32 對變動的管理現行做法
以機場跑道整建為例，依據『臺灣桃園國際機場單一跑道運作應變作業程序』，航務處發布飛航通告(NOTAM)，再依不同應變程序進行標準作業的執行，在航務處發布「解除飛航通告(NOTAM)」後，統一由桃園機場公司公共事務處對外發布消息。
2. e33 推廣非懲罰性安全報告現行做法
(1) 如主動報告安全事件者，以不處罰為主。但若事件嚴重，在行為(人)方面從輕審量，但案子(事)檢討從嚴。
(2) 利用航站工作證之核發機制，有效阻絕不良記錄之單位或個人進出航站工作。

十、 C 機場的 e31 安全成效監測與衡量項目與 e34 安全管理系統的持續改進項目表現評估遜於他站，請分項說明施行現況，並說明本機場之非懲罰性的安全報告制度之施行現況。
1. e31 安全成效監測與衡量
本項目之手冊作業已於 2012 年底建置完成，SMS 手冊中安全保證要項之作業尚未執行。
</td></tr>
</table>

評估要項	訪談問項與回答
	2. e_{34} 安全管理系統的持續改進 (1) 目前有關稽核與督查的作業，依據民航局航站檢查之內部查核表作業進行自我督查與外部督察，由航空站檢查員依據內部查核表作業進行自我督查與民航局每年實施之外部督察。 (2) 地勤作業違規: 證照記點，記滿三點後吊銷場內工作證照，三個月後才能重新申請或考照。利用違規報告書，進行案例教學，加強安全教育，重新訓練。
C_4 安全提升	**十一、 探討 A 機場對 e_{42} 培訓與教育作業之特別之處，或是其他可供他站效法之作業。** 1. 與航務作業及安全作業相關的新進人員，需至民航局航訓所進行安全管理課程。 2. TPE 認可之安全管理作業種子教官，將不定期至新加坡民航學院受訓，並返回 A 機場訓練安全管理作業人員。 **十二、對 B 機場而言，e_{43} 安全溝通作業表現遜於他站，探討現行做法。** 1. B 機場網站之 SMS 專區標準作業表格：機場員工、航空公司人員及地勤代理作業人員。 2. 航務組安全危害通報表: 對口單位為航務組。 3. 1 與 2 之安全事件檢討與案例分析由航務組與安全委員會於每月例行性 安全會議進行案例分享，並列入複訓教材。 4. B 機場每季例行與飛航駕駛員或航空公司航務人員進行座談，針對安全事項與航務服務內容進行交流。如: 滑行道中心線標示問題。 **十三、C 機場的 e_{42} 培訓與教育作業與 e_{44} 安全能力與持續改進作業表現，遜於他站，探討現行作法。** 1. 目前手冊相關作業已建制，所有航務組新進人員於正式上線前，均需接受民航局航訓所安全管理系統課程。 2. 另於機坪駕照考試中新增 SMS 通報試題，提供通報管道,鼓勵所有作業單位於發現危害時通報安全辦公室。

評估要項	訪談問項與回答
	十四、 各機場的安全文化特性為何? 1. A 機場: **全民參與、全員飛安、全員保安** 將安全風險管理觀念讓所有民眾與機場人員都能落實在生活中，如機場清潔人員面對遺失物拾金不昧，由道德品格與安全風險管理相連接。 - 應用範例: 外勞在管制區逃跑、空橋作業員的標準作業…等等。 2. B 機場: 推行機場全員安全意識，互相提醒，互相監守，主動提報。目前實施的現況是以在地文化，將安全風險觀念和緩的融入工作中。 3. C 機場: (1) 提供快速而有效的協助予機場利害關係人 (如航空公司、地勤代理公司、油品公司…等)，以利機場作業進行。 (2) 群體安全意識強烈，航務中心與機場使用者信賴關係良好。